ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

STORMS AND METEOROLOGICAL PARAMETERS AFFECTING THE AVIATION

Ph.D. THESIS

Emrah Tuncay ÖZDEMİR

Department of Meteorological Engineering

Atmospheric Sciences Programme

AUGUST 2016

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

FIRTINALAR VE HAVACILIĞI ETKİLEYEN METEOROLOJİK PARAMETRELER

DOKTORA TEZİ

Emrah Tuncay ÖZDEMİR
(511122004)

Meteoroloji Mühendisliği Anabilim Dalı

Atmosfer Bilimleri Programı

Tez Danışmanı: Doç. Dr. Ali DENİZ

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Emrah Tuncay ÖZDEMİR, a Ph.D. student of ITU Graduate School of Science Engineering and Technology student ID 511122004, successfully defended the thesis entitled "STORMS AND METEOROLOGICAL PARAMETERS AFFECTING THE AVIATION", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Assoc. Prof. Dr. Ali DENİZ** Istanbul Technical University	....
Jury Members :	**Prof.Dr. Selahattin İNCECİK** Istanbul Technical University	....
	Assoc. Prof. Dr. Hüseyin TOROS Istanbul Technical University	....
	Prof. Dr. Zafer ASLAN Istanbul Aydın University	....
	Assoc. Prof. Dr. Haldun KARAN The Scientific And Technological Research Council Of Turkey	....

Date of Submission : 25 May 2016
Date of Defense : 08 Aug 2016

To a True Friend and my family,

FOREWORD

My university education which started at ITU Science and Literature Faculty, Physics Engineering in 1988 continued by Master's degree in Meteorology Engineering at ITU Faculty of Aeronautics and Astronautics in 2007. Because of the Doctorate Programme of Atmospheric Sciences in ITU Institute of Natural and Applied Sciences, Meteorology Engineering, which I will be finishing in June, 2016 I have bittersweet feeling. I always liked being a student at ITU I had chance of meeting a lot of valuable professors and friends during my education life and it will be very hard for me to leave ITU. Joining to my beloved university as an academic member will always take its place within my future plans.

Firstly, I would like to thank my supervisor Assoc. Prof. Dr. Ali DENİZ whom I met at Advanced Synoptic Meteorology lecture in Spring Term of 2009 of Master's Programme of Meteorology Engineering. During 7 years of our study, he helped me not only as a teacher but also as a brother. His approaches of writing scientific articles have always remarkably encouraged me. Assoc. Prof. Dr. Ali DENİZ and I have completed the projects: 4 SCI and SCI-E articles, 2 national articles, 10 international and 12 national conference papers, 1 TUBITAK (COST) project and 1 ITU BAP project. Our future article and project studies are also planned.

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I want to thank my dear wife Hilal ÇALIK ÖZDEMİR who patiently watches and helps my studies in every aspects, and my dear son Tunç Aykut ÖZDEMİR.

I would like to write down a saying of my wife. She uses these words for me: 'Tuncay's real profession is being a student, he goes to work as a hobby'.

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August 2016

Emrah Tuncay ÖZDEMİR
(Physics Engineer)

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ABBREVIATIONS

CAPE	**:** Convective Available Potential Energy
CIN	**:** Convective Inhibition
FIR	**:** Flight Information Regions
ILS-CAT	**:** Instrument Landing System Category
METAR	**:** Aviation Routine Weather Report
SIGMET	**:** Significant Meteorological Information
SPECI	**:** Aviation Selected Special Weather Report
TS	**:** Thunderstorm
UTC	**:** Coordinated Universal Time
VAAC	**:** Volcanic Ash Advisory Centre
VAG	**:** Volcanic Ash Graphic

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STORMS AND METEOROLOGICAL PARAMETERS AFFECTING THE AVIATION

SUMMARY

Storms and meteorological parameters affecting the aviation (such as wind gust, thunderstorms, runway visual range, volcanic ash) are the atmospheric events which affect human lives negatively. Understanding these meteorological events' formation mechanisms and predicting the weather before happening of these atmospheric events and taking the proper precautions are particularly important for aviation. Within the scope of this thesis, storms and the meteorological parameters affecting the aviation, respectively, severe thunderstorm for Esenboğa International Airport, thunderstorm and fog for Atatürk International Airport and Volcanic ash for Turkish FIR areas were examined. This thesis study is based on 3 SCI & SCI-E articles and 1 national article.

Thunderstorms are produced when clouds develop vertically and some may exceed the tropopause and spread out widely. That is why thunderstorms are very important for the aviation industry because of their dynamical mechanism and air safety. The main purpose of this study is to unveil the thunderstorm activity at Istanbul Ataturk International Airport (LTBA) and its relationship to convective available potential energy (CAPE) values handled from soundings statistically. In this study, thunderstorms at LTBA are analysed by periods and using METAR (Aviation Routine Weather Report) and SPECI (Aviation Selected Special Weather Report) reports in the period 2008–2013. Also CAPE and CIN (Convective Inhibition) values are estimated statistically and classified according to moderate and deep convection thresholds. During the 5 years study period, there were 127 thunderstorm (TS) days and chance of a TS was 6.95%. Although the highest CAPE values were observed in summer, TS frequency was highest during. Maximum frequency of thunderstorms is observed during September (22 days) and June (19 days). It is observed that 42.16% of thunderstorms occurred between 1700 and 2400 UTC (Coordinated Universal Time) and 17.48% are between 0900 and 1300 UTC. The longest-lasting thunderstorm was detected on September 8 and 9, 2009 and June 23, 2010, lasting 7 hours 30 minutes (Özdemir et al., in press, a).

In this study, a severe thunderstorm that occurred at Esenboğa International Airport (ICAO code: LTAC) on the 15th of July, 2013, was investigated. A heavy thunderstorm with hail and rain showers occurred at 14:32 UTC. The maximum wind speed of 61 knots was measured at 14:34 UTC. During a 14-minute time interval, 16.2 mm of precipitation occurred. The aircraft parking area was under water, and rainwater leaked from the terminal roof, which affected passengers. For LTAC and its surroundings, 57 dBZ maximum reflectivity values at radar echo intensity were measured (Özdemir&Deniz, 2016).

The aims of this study were to classify the fog that occurs at Istanbul Ataturk International Airport according to its formation mechanism, identify the instrument landing system category (ILS-CAT) operations required to land aircraft in the fog, and determine the CAT operations of the foggy hours at the airport. METAR and SPECI observations were used to investigate fog events occurring at the airport for the years of 2006 to 2015. Of the flights that required an Instrument Landing System to land, 97.63% were under the CAT IIIA operation, 100% of flights were under the CAT IIIB operation and 100% flights were under the CAT IIIC operation (Özdemir et al., in press, b).

Volcanic ash clouds could be drifted to hundreds, thousands of miles away and even intercontinental depending on meteorological conditions. They can have an effect over a very large air space. Ash clouds can drift over multiple countries, FIR (Flight Information Regions) and control areas and may cause danger. Volcanic ash clouds, which are effective in a very large area, have vital importance for aviation. Existence of volcanic ash clouds, or locating the dangerous areas may cause route changes, delays or even flight cancellations. In this study, the effect of volcanic eruptions between 2010-2015 in Turkish FIR areas were examined. The 5 year period of VAG (Volcanic Ash Graphic), which is designed by London Volcanic Ash Advisory Centre (VAAC) and works in coordination with Toulouse VAAC located in France, was used. In order to investigate the effects on Turkish FIR areas of Ankara FIR (LTAA) and Istanbul FIR (LTBB) areas, the SIGMET (Significant Meteorological Information) messages, which were generated by Esenboğa and Atatürk International Airport Meteorological Offices respectively, were examined. As the result of SIGMET messages generated by Atatürk International Airport Meteorological Office, flights between 10.000 and 30.000 feet altitude were cancelled in 18th April 2010 for northern Thrace and south west Black Sea region as well as in 19th of April 2010 for south west Black Sea region (Özdemir&Deniz, 2015).

FIRTINALAR VE HAVACILIĞI ETKİLEYEN METEOROLOJİK PARAMETRELER

ÖZET

Fırtınalar ve havacılığı etkileyen meteorolojik parametreler (rüzgar hamlesi, gökgürültülü fırtınalar, pist görüş mesafesi, volkanik kül vb.) insan hayatını olumsuz yönde etkileyen atmosferik olaylardır. Bu meteorolojik olayların oluşum mekanizmalarını anlamak ve ileride bu tür atmosferik hadiseler öncesinde hava öngörüsünde bulunarak gerekli olan önlemleri almak havacılık için önem arz etmektedir. Bu tez kapsamında fırtınalar ve havacılığı etkileyen meteorolojik parametrelerden, sırasıyla Esenboğa Uluslararası Havalimanı için şiddetli gök gürültülü fırtına, Atatürk Uluslararası Havalimanı için oraj ve sis hadiseleri ve Türkiye Fır Sahaları için ise volkanik kül incelenmiştir. Bu tez çalışması 3 adet SCI & SCI-E makale ve 1 adet ulusal makaleden oluşmaktadır.

Orajlar, şiddetli hava sarsıntılarının (downdraft and updraft), şiddetli buzlanmaların, dolu ve aşırı sağanak yağışların görüldüğü, şimşek, yıldırım ve tehlikeli rüzgar kırılmalarının bulunduğu olaylardır. Çok iyi gelişmiş olan TS'in tropopoz seviyesini aşıp daha yukarı seviyelere kadar dikey olarak gelişen ve havacılık için çok önem taşıyan meteorolojik hadiselerdir. Orajların oluşabilmesi için a) Hava parselinin yüksek oranda nem içermesi b) Hava parselini yukarıya taşıyacak bir kaldırma kuvvetinin var olması (Konveksiyon, konverjans, oroğrafik yükselme ve cephesel kaldırmalar) c) Atmosferin kararsız bir yapıda olması gibi şartların sağlanması gerekir. Orajların oluşturduğu tehlikelerinden bazıları " wind shear, buzlanma, türbülans, dolu , şimşek , elektrik yüklenmesi, windstorms , microburst ve macrobursts" olarak sıralanabilir. Orajlar dinamik mekanizmaları nedeniyle havacılık sektöründe meydana getirdikleri kazalar ve divertler nedeniyle önemini hiçbir zaman kaybetmemişlerdir. Bu çalışmada 2008-2013 yılları arasında METAR (Aviation Routine Weather Report) and SPECI (Aviation Selected Special Weather Report) rasatları kullanılarak Istanbul Atatürk International Airport (LTBA) 'da meydana gelen thunderstormlar araştırılarak, yıllara, aylara, günlere ve saatlere (UTC-Universal Coordinated Time) göre dağılımları ve frekansları incelenmiştir. Ayrıca oraj meydana gelen günlere ait yüksek seviye ölçüm değerleri İstanbul Ravinsonde rasatları incelenerek, gün içindeki CAPE (Conditionally Available Potential Energy) ve CIN (Convective Inhibition) değerleri istatistiksel değişimleri saptanmıştır (Özdemir et al., in press, a).

Her geçen yıl havacılık sektörü büyümektedir. Bu büyümeyle birlikte sektör açısından ciddi oranda tehdit oluşturan tehlikeli meteorolojik olaylara çözüm bulma ihtiyacı daha da artmaktadır. Bu tehlikeli olaylardan birisi de havalimanlarında meydana gelen boran hadisesidir. Bu çalışmada 15 Temmuz 2013 tarihinde Ankara Esenboğa Havalimanı'nda meydana gelen boran hadisesi incelenmiştir. Çalışma kapsamında Esenboğa Meteoroloji Ofisi tarafından hazırlanan METAR ve SPECI

rasatları , sinoptik haritalar, Skew-T Log-P diyagramı, uydu ve radar görüntüleri değerlendirilmiştir. 14:32 UTC (Universal Coordinated Time)'da şiddetli gök gürültülü doluyla birlikte yağmur sağanağı meydana gelmiştir. Bu hadisenin olduğu zamanda gün içindeki en yüksek maksimum rüzgar şiddeti değeri olan 61 knots ölçülmüştür. 54 dakikalık zaman aralığında 16.4 mm yağış meydana gelmiştir. Radar ürünlerinde Esenboğa Havalimanı ve çevresinde maksimum 57 dBZ reflektivite değerine ulaşan radar eko şiddeti ölçülmüştür. Olayın etkileri ise; 15 Temmuz 2013 tarihinde Ankara ve çevresinde meydana gelen severe thunderstorm ile birlikte kuvvetli sağanak yağışlar birçok yerde hayatı olumsuz etkilemiştir. Keçiören ve Pursaklar İlçeleri'nde daha etkili olan sağanak yağış ulaşımda aksamalara neden olmuştur. Esenboğa Havalimanı Karyağdı civarında bulunan alt geçidin suyla dolması sonucu araçlar bu geçidi kullanamazken fırtınanın ve dolu yağışının etkisiyle Saray Bölgesi'nde birçok evin camları kırılmıştır. Ankara Çubuk Karayolu orta refüjde bulunan ağaçlar yerinden sökülmüş, Yenice mahallesinde bulunan dev totem tabelaları devrilerek biri bir aracın üzerine düşmüştür. Esenboğa Havalimanı'nda ise terminal çatısından sızan yağmur suları yolculara zor anlar yaşatarak hava trafiğinin aksamasına neden olmuş, iki uçak ilk denemelerinde iniş yapamamış, bir uçak başka bir havalimanına yönlendirilmiştir. Yağmur sularının elektrik tesisatına sızması nedeniyle havalimanında sık sık elektrik kesintisi yaşanmıştır (Özdemir&Deniz, 2016).

Sis canlıların yaşamını etkileyen önemli meteorolojik olaylardan biridir. Stratüs bulutunun yer seviyesine inmesi sonucu da sis oluşmaktadır. Tarımsal açıdan ekinlerin ve bitkilerin donmasını önlemektedir. Sis sonucu yatay ve dikey görüş mesafesinin azalması kara, deniz ve hava ulaşımında birçok olumsuzluklara neden olmaktadır. Ulaşımın aksaması, iptal edilmesi ve kazalar sis sonucu olan olaylardır. Havalimanlarında meydana gelen sisler de uçuşların iptal edilmesine, hava trafiğinin hızının azalmasına, uçuşların diğer havalimanlarına yönlendirilmesine ve en önemlisi de kaza kırımlara yol açmaktadır. Meteorolojide "Rüyet" veya "Görüş Mesafesi" belirli bir özelliğe sahip bir nesnenin gözle (aletsiz olarak) tanımlanabileceği veya geceleyin yapılan gözlemlerde aynı nesnenin gün ışığı varmış gibi tanımlanabileceği en uzak mesafe olarak adlandırılır. Su damlacıklarının veya buz kristallerinin yer yüzeyine yakın bir tabakada asılı olarak kalmaları sonucunda görüş mesafesinin 1000 metrenin altına düşmesi sonucunda oluşan hava hadisesine sis denir. Benzer koşullarda görüş mesafesi en az 1000 metre fakat 5000 metreden fazla olmamak koşuluyla oluşan hadiseye de pus denir (havacılık amaçlı yapılan rasatlarda). Pist görüş mesafesinin sis tanımına uygun bir şekilde azalması ve bulut alt tabanının da yere oldukça yaklaşması havacılık sektörü için önem arz etmektedir. Bu iki faktöre etki eden diğer meteorolojik hadiselerde yağmur, çisenti ve kar kombinasyonlarıdır.
Havalimanlarında meydana gelen sisler uçuşların iptal edilmesine, hava trafiğinin hızının azalmasına, uçuşların diğer havalimanlarına yönlendirilmesine ve en önemlisi kaza kırımlara yol açmaktadır. Bu çalışmada 2006-2015 yılları arasında METAR ve SPECI rasatları kullanılarak İstanbul Atatürk Havalimanı (LTBA) 'da meydana gelen sisler araştırılarak, yıllara, aylara, günlere ve saatlere göre dağılımları ve frekansları incelenmiştir.10 yıllık periyotta 49 gün sisli gün olarak tespit edilmiş ve toplam 157 saat 6 dakika devam etmiştir. Çalışmanın amacı havacılık amaçlı aletli iniş sistemi kategorisinde sisleri sınıflandırarak Atatürk Havalimanı'nın sisli saatlerindeki CAT kategorilerini tespit etmektir. Buna göre CATIIIA uçuş kategorisine göre uçuşların %97.63'ü gerçekleşebilmektedir (Özdemir et al., in press, b).

Volkanik kül bulutları patlamanın olduğu yanardağdan yüzlerce, binlerce mil uzaklara, hatta meteorolojik şartlara bağlı olarak kıtalararası mesafeler boyunca sürüklenebilir. Çok geniş bir hava sahasında etkili olabilir. Kül bulutları birkaç ülkenin, FIR (Flight Information Region-Uçuş Bilgi Bölgesi) ve kontrol sahasına yayılarak tehlike oluşturabilir. Çok geniş bir sahada etkili olan volkanik kül bulutları havacılık için hayati önem taşımaktadır. Volkanik kül bulutlarının mevcut olması veya günümüzde öngörüsü yapılan etki alanlarının tespit edilebilmesi uçuşlarda rota değişimlerine, gecikmelere ve hatta uçuş iptallerine neden olmaktadır. Bu çalışmada 2010 ile 2015 yılları arasında meydana gelen yanardağ patlamalarının Türkiye FIR Sahaları üzerindeki etkisi incelenmiştir. 5 yıllık periyotta Fransa'da bulunan Volkanik Kül Tavsiye Merkezi (VAAC-Volcanic Ash Advisory Centre) Toulouse'la koordineli çalışan Londra Volkanik Kül Tavsiye Merkezi tarafından hazırlanan Volkanik Kül Grafikleri (VAG-Volcanic Ash Graphic) kullanılmıştır. Türkiye'deki FIR Sahalarına olan etkilerin araştırılması içinde Türkiye'de bulunan Ankara FIR (LTAA) ve İstanbul FIR (LTBB) sahaları için sırasıyla Esenboğa ve Atatürk Uluslararası Havalimanları Meteoroloji Ofisleri tarafından hazırlanan SIGMET (Significant Meteorological Information) mesajları değerlendirilmiştir. Elde edilen Atatürk Uluslararası Havalimanı Meteoroloji Ofisi'nin hazırlamış olduğu SIGMET mesajlarına göre, 18 Nisan 2010 tarihinde Trakya'nın kuzeyi ve Karadeniz'in güney batısı, 19 Nisan 2010 tarihinde de Karadeniz'in güney batısı uçuş seviyesi olarak 10.000 feet ile 30.000 feet arasındaki mesafeler için uçuşlara kapatılmıştır (Özdemir&Deniz, 2015).

1. INTRODUCTION

Storms and meteorological parameters affecting the aviation (such as wind gust, thunderstorms, runway visual range, volcanic ash) are the atmospheric events which affect human lives negatively. Understanding these meteorological events' formation mechanisms and predicting the weather before happening of these atmospheric events and taking the proper precautions are particularly important for aviation. Within the scope of this thesis, storms and the meteorological parameters affecting the aviation, respectively, severe thunderstorm for Esenboğa International Airport, thunderstorm and fog for Atatürk International Airport and Volcanic ash for Turkish FIR areas were examined. This thesis study is based on 3 SCI, SCI-E articles and 1 national article.

A thunderstorm (TS), also known as an electrical storm, is a severe weather phenomenon characterised by lightning and its acoustic effect, extreme showers, updrafts and downdrafts and sometimes severe ice at higher levels produced by cumulonimbus cloud (NOAA, 2013). Well-developed TS may spread out over the tropopause level in some circumstances and it may produce wind shear, icing, turbulence, hail, lightning, windstorms, macroburst and microburst. This is really a matter for flight safety and it is needed to identify and predict the exact location of TS and its time. For TS to occur, the conditions below are required:

(i) Air parcel must have high amount of moisture,

(ii) Buoyancy to move air parcel upward (i.e. convection, convergence, orographic ascent or frontal lifting),

(iii) Unstable atmosphere.

In this study, thunderstorms at LTBA (Istanbul Atatürk International Airport) are analysed by the periods and using METAR (Aviation Routine Weather Report) and SPECI (Aviation Selected Special Weather Report) reports in the period 2008–2013. LTBA is the largest airport in Turkey and at south west of Istanbul. The airport is located at $40^{\circ} 58^{'} 34^{''}$ N and $28^{\circ} 48^{'} 50^{''}$ E and its altitude is 33 m. It was opened for service in 1953 and has a total area of 345270 m^2. According to the DHMI (2013) report, cumulative flights were 364322 total numbers of passengers were 45091962; total cargo handled was 1231503.50 tonnes including domestic and international traffic (cumulative totals of 2012 year) (Özdemir et al., in press, a).

The need to forecast dangerous meteorological phenomena, which are a great threat to the growing aviation sector, increases significantly. Such dangerous events include severe thunderstorms occurring at airports. A severe thunderstorm is defined as a thunderstorm with wind gusts ≥ 50 knots and/or hail ≥ 1 inch diameter (Url-1). Ankara is the capital of Turkey, and Esenboğa International Airport (ICAO code: LTAC) is the city's largest airport. On the 15th of July, 2013, a thunderstorm with heavy rain occurred at LTAC with a wind gust value of 61 knots and a severe hail event. In a 14-minute period, 16.2 mm of rainfall was recorded. The purpose of this work is to examine the meteorological conditions that caused the severe thunderstorm at LTAC on the 15th of July, 2013 (Özdemir&Deniz, 2016).

Fog is one of the major meteorological phenomena that impacts human activities. The reduction of horizontal and vertical visibility due to fog causes problems for land, sea and air transportation. Transportation disruptions, cancellations and accidents are issues that can result from fog. At airports, fog can lead to the cancellation of flights, a decrease in the velocity of air traffic, diversions of flights to other airports and, most importantly, flight blocker events.

The weather phenomenon called ‘fog’ is a result of cloud water droplets or ice crystals suspended in the air at or near the land surface in which the observed visibility for aviation falls below 1000 metres (m). Similarly, ‘mist’ is formed when the observed visibility is between 1000 and 5000 m (Annex-3 ICAO, 2013; Glossary NOAA, 2014). It is important for the aviation industry to properly define fog and the lowering of the cloud base because of the impact on runway visibility. Other weather phenomena that can affect visibility are combinations of rain, drizzle and snow (Pearson, 2002).

To quantify weather-related aviation fatalities, Pearson (2002) analysed general aviation and small aircraft transportation data for the United States (including Alaska and Hawaii–and coastal waters) for the period 1995 to 2000. The data show that 4,018 people were killed in plane crashes, of which 1,380 were caused by weather events. Of these fatal accidents, 63% were caused by low cloud base and visibility, 18% by wind and turbulence, 8% by icing, 5% by rain and snow, 5% by thunderstorms and 1% by other weather events (Pearson, 2002).

In this study, statistical analyses were used to investigate foggy days at Istanbul Ataturk International Airport (LTBA) for the period 2006–2015. The objectives of the study were to:

- Classify the fog that occurred at LTBA according to its formation mechanism.
- Classify the fog by the Instrument Landing System (ILS) category for aircraft.
- Identify the aviation landing approach categories (CAT operations) for foggy hours at LTBA (Özdemir et al., in press, b).

Volcanic ash clouds could be drifted to hundreds, thousands of miles away and even intercontinental depending on meteorological conditions. They can have an effect over a very large air space. Ash clouds can drift over multiple countries, FIR (Flight Information Regions) and control areas and may cause danger. Volcanic ash clouds, which are effective in a very large area, have vital importance for aviation. Existence of volcanic ash clouds, or locating the dangerous areas may cause route changes, delays or even flight cancellations. In this study, the effect of volcanic eruptions between 2010-2015 in Turkish FIR areas were examined. The 5 year period of VAG (Volcanic Ash Graphic), which is designed by London Volcanic Ash Advisory Centre (VAAC) and works in coordination with Toulouse VAAC located in France, was used. In order to investigate the effects on Turkish FIR areas of Ankara FIR (LTAA) and Istanbul FIR (LTBB) areas, the SIGMET (Significant Meteorological Information) messages, which were generated by Esenboğa and Atatürk International Airport Meteorological Offices respectively, were examined (Özdemir&Deniz, 2015).

2. SEVERE THUNDERSTORM OVER ESENBOĞA INTERNATIONAL AIRPORT (LTAC) IN TURKEY ON THE 15TH OF JULY, 2013 [1]

2.1 Introduction

The need to forecast dangerous meteorological phenomena, which are a great threat to the growing aviation sector, increases significantly. Such dangerous events include severe thunderstorms occurring at airports. A severe thunderstorm is defined as a thunderstorm with wind gusts ≥ 50 knots and/or hail ≥ 1 inch diameter (Url-1). Ankara is the capital of Turkey, and Esenboğa International Airport (ICAO code: LTAC) is the city's largest airport (Figure 2.1). On the 15th of July, 2013, a thunderstorm with heavy rain occurred at LTAC with a wind gust value of 61 knots and a severe hail event. In a 14-minute period, 16.2 mm of rainfall was recorded.

In Pearson's study for the United States, which included the years 1995 to 2000, the results of accident reports were evaluated, and the causes of accidents originating from meteorological events were examined (Pearson, 2002). The results of this study showed the following: 63% of accidents were caused by a low cloud base and poor meteorological visibility, 18% of accidents were caused by wind and turbulence, 5% of accidents were caused by ice, 5% of accidents were caused by rain and snow events, 5% of accidents were caused by thunderstorms and 1% of accidents were attributed to other causes. Young (2007) examined a severe thunderstorm event that happened in Southern England on the 10th of May, 2006, by using satellite and radar images. In a study by Jebson (2011), a synoptic analysis of a violent thunderstorm was made, and the amount of damage and precipitation were also evaluated in detail for the historical Derby Day storm of the 31st of May, 1911. In many weather events with hail and thunderstorms, considerable property damage occurs (Prichard, 2012; Webb & Blackshaw, 2012; Clark & Webb, 2013), and there are many studies in the

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[1] This chapter is published as :

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scientific literature related to thunderstorms (Haklander & Van Delden, 2003; Sibley, 2012).

The purpose of this work is to examine the meteorological conditions that caused the severe thunderstorm at LTAC on the 15th of July, 2013.

2.2 Data, Methodology, Results

To examine the severe thunderstorm event that happened at LTAC on the 15th of July, 2013, and investigate the structure of synoptic-scale weather systems, surface cards provided by the Met Office and the GFS (Global Forecast System) analysis products that were prepared by Wetter3 (relative humidity of 700 hPa, geopotential height of 500 hPa) were used (Url-2).

The whole country was affected by the trough of an Asian low-pressure system (Figure 2.2). At 12:00 UTC and 18:00 UTC, an isobar (1008 hPa) extending from the northeastern to the western coast passed over Turkey. At 12:00 UTC, 75% relative humidity was observed at the 700 hPa level between the western and southwestern regions (Figure 2.3a). At the 500 hPa level at 12:00 UTC, a splayed trough was approaching Turkey's western regions (Figure 2.3b). There were 584 dam contours and -7.5 °C isotherms over the inner regions of Turkey.

A sounding analysis for Ankara (which includes the Turkish Meteorological Service building) was prepared by the University of Wyoming (Figure 2.1) for an altitude of 891 m (the distance of LTAC is approximately 21 km). The Skew-T Log-P diagram was evaluated for 12:00 UTC (Figure 2.4). Some of the instability indices according to the Skew-T Log-P diagram are given in Table 2.1 (Url-3). Between layers 711 hPa (3002 m) and 572 hPa (4761 m), the relative humidity was equal to 86% and above.

The severe thunderstorm that occurred on the 15th of July, 2013, at LTAC caused a decrease in the air traffic speeds, and flights were diverted to other airports. In this study, for the analysis of the severe thunderstorm event, METAR (Aviation Routine Weather Report) and SPECI (Aviation Selected Special Weather Report) observations and AWOS (Automated Weather Observing System) surface data were evaluated.

The altitude of LTAC is 953 m. LTAC has two parallel runways with lengths of 3750 m (03R-Right/21L-Left and 03L-Left/21R-Right). A 10 m wind velocity was measured at all wind measurement masts (Figure 2.1). According to the 14:20 UTC METAR, the wind speed value for the 03-Right runway was 2 knots in VRB (variable), and there was no incident at the airport (Table 2.2). According to the 14:26 UTC SPECI, a light thunderstorm with rain (-TSRA) had begun, and the wind gust value had increased to 24 knots. Following this SPECI and according to the 14:32 UTC SPECI, a severe weather event increased in intensity and had turned into a severe thunderstorm with hail and rain showers (+TSGRRA), as shown in bold in Table 2.2. With a severe meteorological incident and the effects of evaporation, prevailing visibility (the visibility that is effective on at least half or more of an airport) had dropped from 10,000 m to 500 m. The wind speed at the 03-Right runway was 39 knots, with a wind gust of 50 knots from 180 degrees. At the 03-Left runway, the wind value was 23 knots, with a wind gust value of 61 knots from 210 degrees. The cumulonimbus (Cb) cloud base level had dropped to 2,500 feet. At 14:50 UTC, the incident had transformed into a light thunderstorm with rain, and at 15:20 UTC, it had turned to thunder (TS), which ended at 15:50 UTC.

Meteorological parameters recorded by AWOS every minute between 14:20 UTC and 15:20 UTC were evaluated. Considering AWOS wind measurement values (Figure 2.5a, 2.5b), runway 03L had a wind speed of 30 knots from 267 degrees at 14:31 UTC. A sudden wind increase by backing was recorded. Winds had increased first at 14:32 UTC to 61 knots from 228 degrees and finally at 14:34 UTC to 61 knots from 196 degrees. At 14:21 UTC, the air temperature was 29.8 °C. Within 15 minutes, at 14:36 UTC, it dropped to 11.4 °C (Figure 2.5c). The air temperature at 14:35 UTC, and dew point temperature values at 14:33 UTC, 14:35 UTC and 14:37 UTC could not be obtained due to a power outage. According to QFF (current atmosphere) pressure values (Figure 2.5d), the air pressure peaked at 14:34 UTC, with a 1007.33 hPa value during the thunderstorm pass. An air pressure value for 14:36 UTC could not be obtained. In a 14-minute period, 16.2 mm of rainfall was recorded. At 14:34 UTC and 14:35 UTC (a two-minute period), 8 mm of rainfall was measured (Figure 2.5d).

MSG3 (Meteosat Second Generation 3), Natural Colour RGB (Red Green Blue), MSG3 Day Microphysics RGB/Summer and MSG3 Day Convective Storms RGB satellite images that were obtained from TMS were evaluated for 14:15 UTC and 14:30 UTC. According to the Natural Colour RGB satellite image for LTAC and its environment, ice crystal structures form clouds around the light blue coloured field (Figure 2.6a, 2.6d). On the Day Microphysics RGB/Summer satellite images a large crystal structure of thick convective clouds is shown around a red coloured field (Figure 2.6b, 2.6e). Finally, Day Convective Storms RGB satellite images show developed Cb clouds around the red coloured field (Figure 2.6c, 2.6f).

Elmadağ Meteorology Radar (altitude: 1807 m, tower: 32 m, distance from Esenboğa International Airport: approx. 55 km) is a C-band dual-polarization Doppler radar facility (Figure 2.1). Radar images from Elmadağ Meteorology Radar obtained from the TMS (Turkish Meteorological Service) were evaluated. The assessments were made using Max products. Max products have the ability to show both echo height and the density in a single image. In cases of severe meteorological weather conditions, it can determine these areas. On the 14:06 UTC radar image, a thunderstorm cell with a 53–55 dBZ reflectivity value approached LTAC (Figure 2.7a). At 14:14 UTC, the thunderstorm cell was closer to the airport, and its vertical height exceeded 10.2 km (Figure 2.7b). At 14:22 UTC, the thunderstorm cell was above the airport, with its vertical height exceeding 10.2 km (Figure 2.7c). LTAC was located in the southwestern part of the thunderstorm cell (Figure 2.7d, 2.7e). When we look at the vertical section of the Max Radar product, we can see that the thunderstorm cell had reached a maximum reflectivity value of 57 dBZ at 14:22 UTC (Figure 2.8).

The severe thunderstorms and precipitation that occurred in Ankara on 15 July 2013 had a negative impact on life in many places. Severe precipitation in the Keçiören and Pursaklar districts led to disruptions in transportation. The underpass in the Karyağdı district (near LTAC) filled with water, and cars could not use this gate. With the effects of storms and hail, the windows of many houses were broken in the Saray region. In the Ankara Çubuk Highway central refuge, trees were dislodged, and a giant signboard fell onto a vehicle in the Yenice region. In LTAC, rainwater leaking from the terminal roof inconvenienced passengers. The aircraft parking area was flooded, which led to the disruption of air traffic. Two planes could not land on their first attempt, and another plane was diverted to another airport (Figure 2.9). Due to the infiltration of rainwater into the electrical wiring, the airport experienced frequent power outages (Url-4; Url-5).

2.3 Tables

Table 2.1 : Some of the instability index values, 15th of July, 2013, 1200 UTC.

Index	Value	Interpretation
Showalter Stability Index (SSI)	-0.24	-2 < SSI < 1, thunderstorms possible (generally weak)
Lifted Index (LI)	0.48	0 < LI < 2, showers/ thunderstorms possible with other source of lift
K Index (KI)	39.40	36 ≤ KI ≤ 40, 80% - 90% air mass thunderstorm probability
Total Total Index (TTI)	49.00	48 ≤ TTI ≤ 49, scattered moderate / few heavy / isolated severe thunderstorms
Convective Available Potential Energy (CAPE)	147.61	CAPE < 1000, instability is weak
SWEAT Index (SW)	147.01	SW < 300, no severe storms expected

Table 2.2 : 13:50 UTC – 15:50 UTC METAR and SPECI reports at LTAC, 15th of July, 2013.

Time (UTC)	Wind Velocity and Wind Gust 03R (Degrees/Knots)	Wind Velocity and Wind Gust 21L (Degrees/Knots)	Wind Velocity and Wind Gust 03L (Degrees/Knots)	Wind Velocity and Wind Gust 21R (Degrees/Knots)	Weather Phenomena	Prevailing Visibility (Meter)	Cloud Base (Feet)	Temperature T(°C)/Td(°C)	Pressure QNH (hPa)
1350	060/04	VRB/02	100/04	VRB/05	-	10.000	4000	30/10	1011
1420	VRB/02	030/06	VRB/04	VRB/07G21	-	10.000	3000CB	30/10	1011
1426	190/12G24	020/08	020/06G16	360/13	-TSRA	10.000	3000CB	29/12	1011
1432	**180/39G50**	**240/12G22**	**210/23G61**	**220/11G21**	**+TSGRRA**	**500**	**2500CB**	**21/14**	**1011**
1450	060/21G31	050/16	070/21	090/21G31	-TSRA	10.000	3000CB	18/16	1011
1520	010/16	340/11	360/14	360/14	TS	10.000	3000CB	20/16	1012
1550	030/16	020/14	020/13	040/15	-	10.000	3000CB	20/16	1012

(VRB: wind direction variable, G: gust, (-) intensity: light, (+) intensity: heavy, TS: thunderstorm, TSRA: thunderstorm with rain, TSGRRA: thunderstorm with hail and rain, CB: cumulonimbus)

2.4 Figures

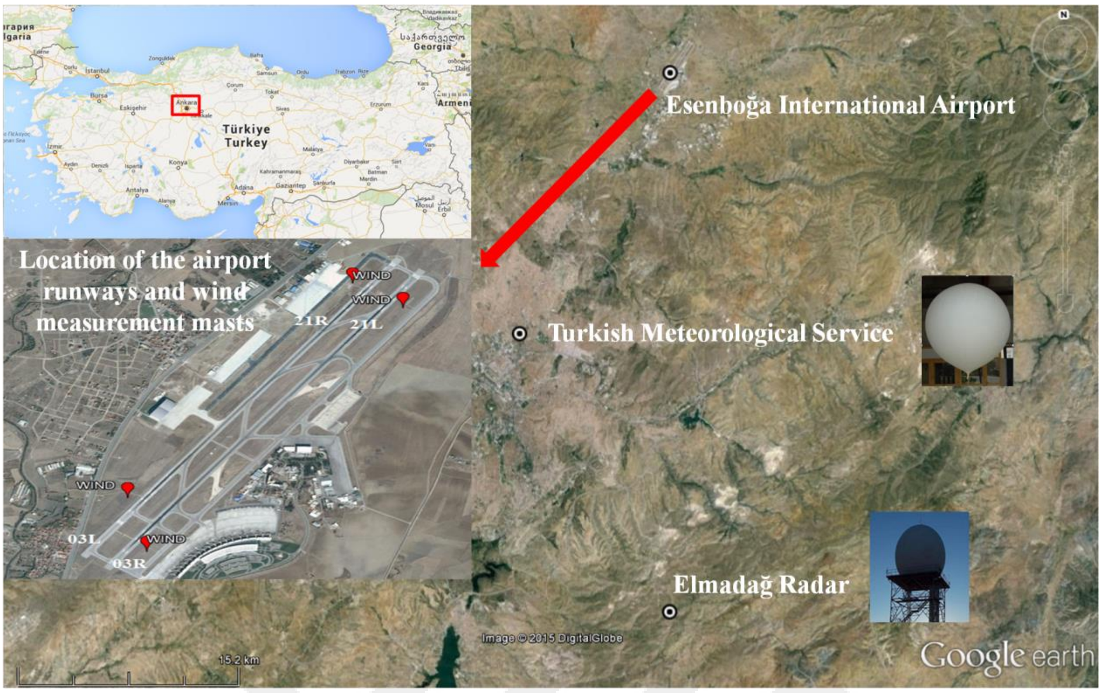

Figure 2.1 : Esenboğa International Airport, Turkish Meteorological Service (Ankara Rawinsonde Center), Elmadağ Radar, runways and wind measurement mast positions for LTAC (Url-6).

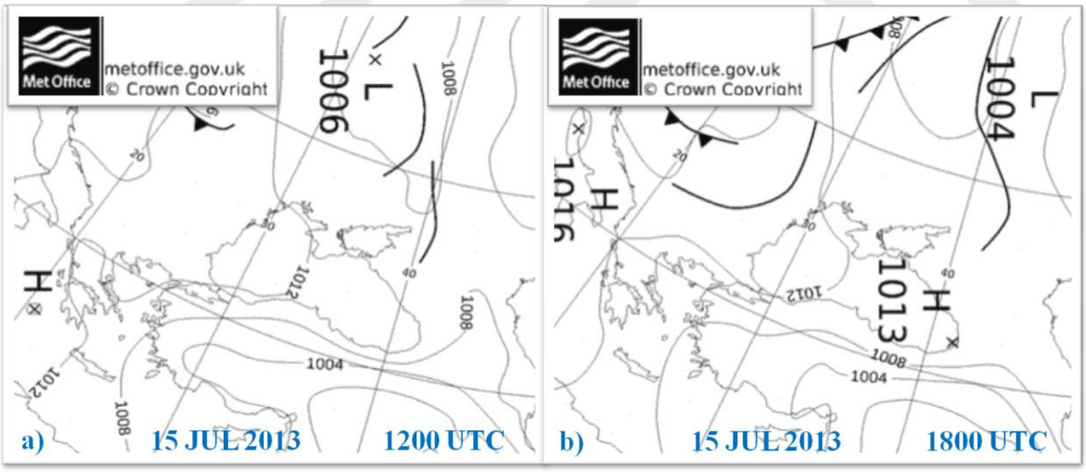

Figure 2.2 : Met Office analysis card, 15th of July, 2013. a) 1200 UTC b) 1800 UTC.

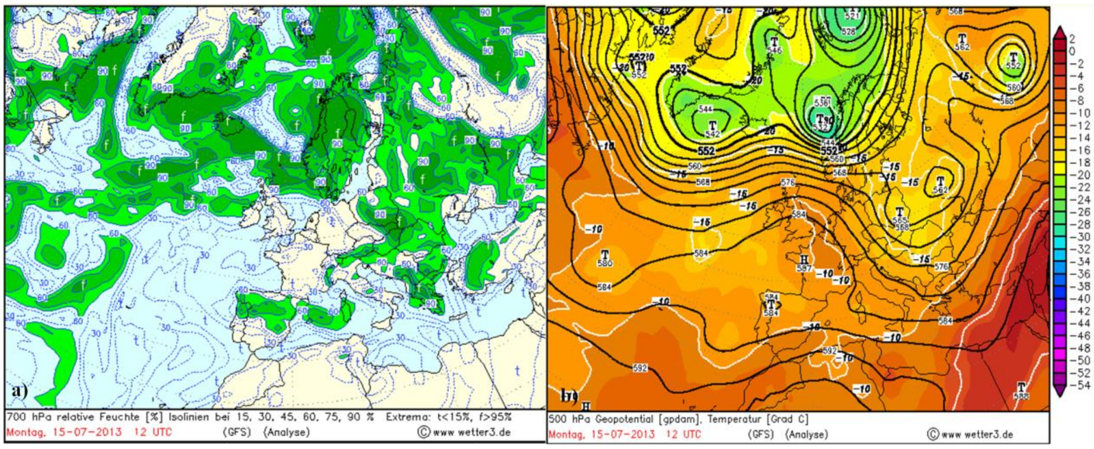

Figure 2.3 : 15th of July, 2013, 1200 UTC. a) 700 hPa moisture card b) 500 hPa geopotential height card (Url-2).

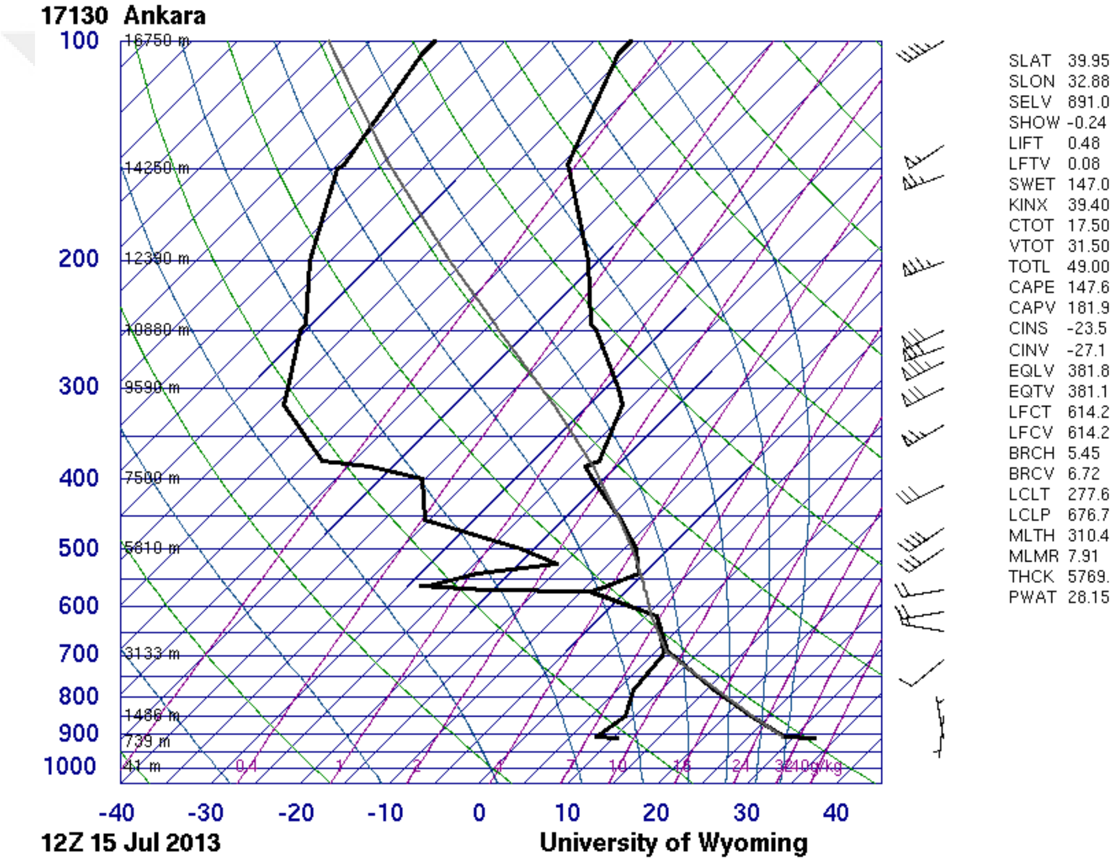

Figure 2.4 : Skew-T Log-P diagram of Ankara, Turkey, 15th of July, 2013.

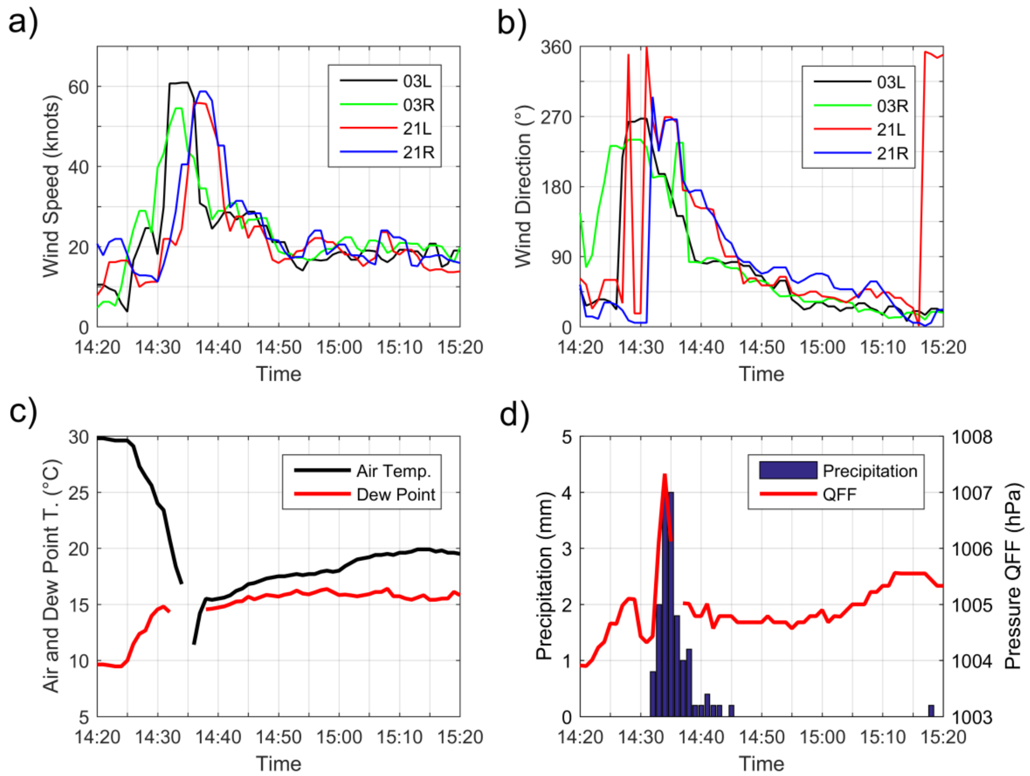

Figure 2.5 : Minute base data belonging to the AWOS device, 15 July 2013, 1420 UTC-1520 UTC a) 2 minutes maximum wind speed values for four runways b) 2 minutes maximum wind direction values for four runways c) temperature and dew point temperature d) pressure (QFF) and precipitation.

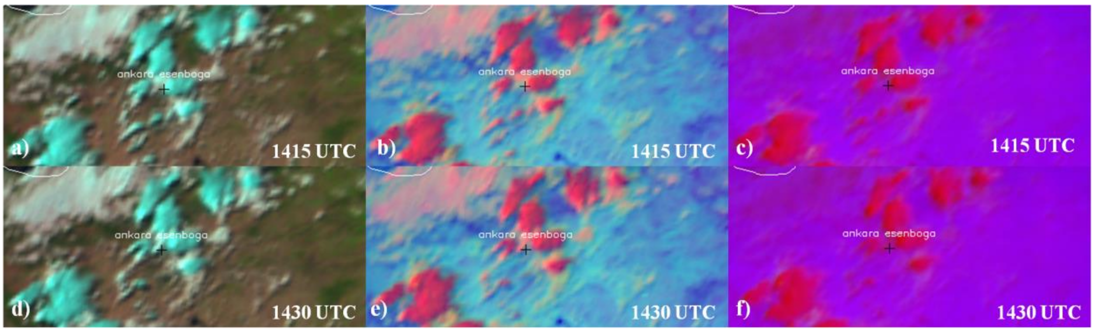

Figure 2.6 : Satellite images from the 15th of July, 2013. Natural Colour RGB a) 14:15 UTC & d) 14:30 UTC; Day Microphysics RGB/Summer b) 14:15 UTC & e) 14:30 UTC; Day Convective Storms RGB c) 14:15 UTC & f) 14:30 UTC.

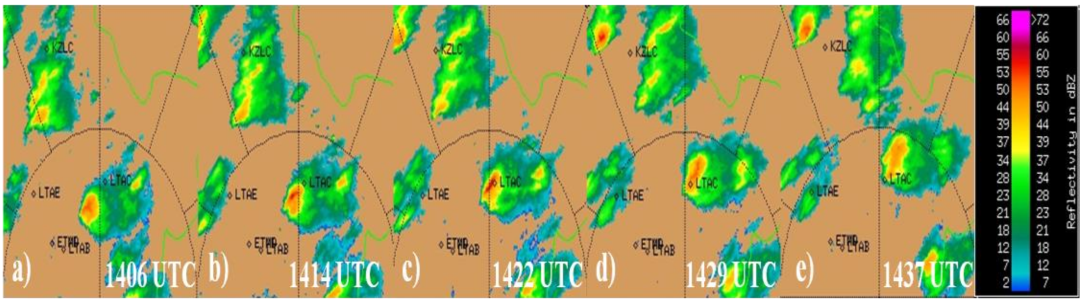

Figure 2.7 : Max radar images, 15th of July, 2013. a) 14:06 UTC b) 14:14 UTC c) 14:22 UTC d) 14:29 UTC e) 14:37 UTC.

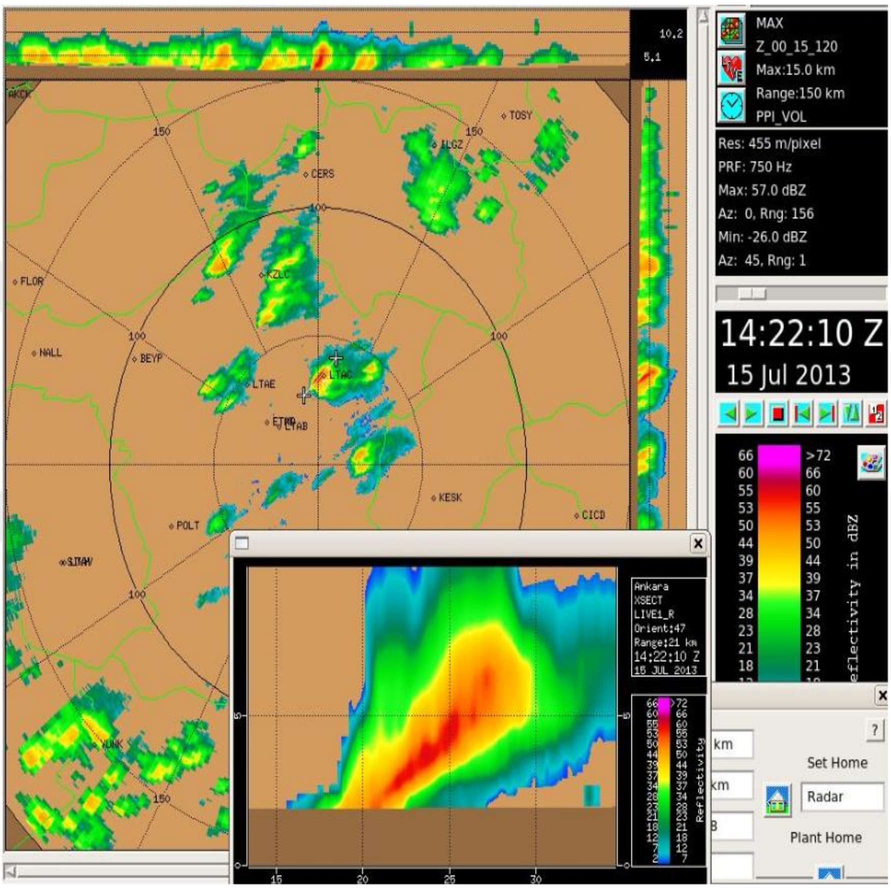

Figure 2.8 : Horizontal and vertical section of the Max Radar image, 14:22 UTC, 15 July 2013.

Figure 2.9 : The flooding of the aircraft parking area and the view of the terminal building at Esenboğa International Airport on the15th of July, 2013 (Url-5).

3. INVESTIGATION OF THUNDERSTORMS OVER ATATURK INTERNATIONAL AIRPORT (LTBA), ISTANBUL [2]

3.1 Introduction

A thunderstorm (TS), also known as an electrical storm, is a severe weather phenomenon characterised by lightning and its acoustic effect, extreme showers, updrafts and downdrafts and sometimes severe ice at higher levels produced by cumulonimbus cloud (NOAA, 2013). Well-developed TS may spread out over the tropopause level in some circumstances and it may produce wind shear, icing, turbulence, hail, lightning, windstorms, macroburst and microburst. This is really a matter for flight safety and it is needed to identify and predict the exact location of TS and its time. For TS to occur, the conditions below are required:

(i) Air parcel must have high amount of moisture,

(ii) Buoyancy to move air parcel upward (i.e. convection, convergence, orographic ascent or frontal lifting),

(iii) Unstable atmosphere.

The climatological means of CAPE (Convective Available Potential Energy) increases with decreasing latitude and shows the largest values near the ITCZ (Inter Tropical Convergence Zone). The largest values of CIN (Convective Inhibition) do not occur around the ITCZ but between the Equator and the 30th parallel, revealing a bimodal zonal distribution, therefore resembling the ascending and descending parts of the Hadley Cell (Riemann-Campe et al., 2009).

Sasse and Hauf (2003) investigated the effects of TS on landing aircrafts at Frankfurt Airport in Germany and Tafferner et al. (2010) compared TS locations measured by

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[2] This chapter is in queue for publishing :

Özdemir, E. T., Deniz, A., Sezen, İ., Aslan, Z., Yavuz, V. (in press). Investigation Of Thunderstorms Over Ataturk International Airport (Ltba), Istanbul, Mausam, Reference No J-065(5801).

ground-based systems. Adams and Souza (2009) investigated CAPE and Convective Events in the Southwest America during the North American Monsoon and they found a moderate positive correlation, approaching 0.6 between precipitation and CAPE. Riemann-Campe et al. (2010) estimated the memory of convective precipitation via the analysis of the convective parameters CAPE and CIN. Kaltenböck et al. (2009) described environmental atmospheric characteristics in the vicinity of different types of severe convective storms in Europe during the warm seasons in 2006 and 2007.

Das et al. (2013) investigated severe thunderstorms that took place at Guwahati Airport on April 5, 2010 using many meteorological observations (i.e. pressure, temperature, humidity, rain and wind), and radar and satellite information; they found that moisture incursions at lower level, instability in the atmosphere (different stability indices) and linear organization of the convective system are responsible for squall and thunderstorm events. The study by Biswas and Dukare (2011) showed that SW Monsoon, depression, low pressure area, upper air cyclonic circulation and cyclonic storm are the main reasons for occurrence of thunderstorms at Aurangabad Airport in India between the years 1990 and 2009; also they found that one quarter of the all thunderstorms happened at the study area for the whole period in June, and that thunderstorm activities generally took less than 3 hours. Agnihotri et al. (2012) statistically studied thunderstorms for Bangalore between the years 1981 and 2010. 41% of thunderstorms happened in Pre-Monsoon and SW Monsoon seasons for this region, also 78% of thunderstorms took less than 3 hours, 20% of them took between 3–6 hours, 2% took more than 6 hours. 34% happened at 1500–1800 hours IST (India Standard Time), respectively. The long-term thunderstorm happened in May, taking 10.1 days. Finally, Laskar and Kotal (2013) studied Purnea, Araria and Kishanganj on April 13, 2010, using synoptic charts, radar and satellite images, and WRF (Weather Research and Forecasting) Model with ECMWF (European Centre for Medium-Range Weather Forecasts) and GFS (The Global Forecast System) data products. According to them, though the WRF Model estimates many parameters well, rainfall could not be estimated by WRF with GFS data. However, WRF with ECMWF data can estimate only light rainfall.

In this study, thunderstorms at LTBA (Istanbul Atatürk International Airport) are analysed by the periods and using METAR (Aviation Routine Weather Report) and

SPECI (Aviation Selected Special Weather Report) reports in the period 2008–2013. LTBA is the largest airport in Turkey and at south west of Istanbul. The airport is located at 40° $58^{'}$ $34^{''}$ N and 28° $48^{'}$ $50^{''}$ E and its altitude is 33 m. It was opened for service in 1953 and has a total area of 345270 m^2. According to the DHMI (2013) report, cumulative flights were 364322 total numbers of passengers were 45091962; total cargo handled was 1231503.50 tonnes including domestic and international traffic (cumulative totals of 2012 year). CAPE and CIN values are also statistically analysed according to weak, moderate, strong and extreme convection thresholds. CAPE and CIN values are obtained from sounding observations performed at Kartal Meteorology Station. Sounding observations are implemented in 8 stations in Turkey and twice a day at 0000 UTC and 1200 UTC. Kartal Meteorology station is where sounding observations started on December 1, 2007. The altitude of Kartal Meteorology Station is 16 m and it is located at 40° $54^{'}$ $40^{''}$ N, 29° $09^{'}$ 20” E. The distance between LTBA and Kartal is 29.77 km and Kartal is 103° degrees east according to LTBA. The locations of Istanbul Ataturk Airport and Kartal Meteorology Station are shown in Figure 3.1.

3.2 Data and Method

METAR observations are performed twice an hour at HH:20 and HH:50 and also SPECI observations are performed between the METAR observations as per criteria stipulated in ICAO (International Civil Aviation Organization) ANNEX 3 (ICAO, 2013).

TS events are detected by investigating METAR and SPECI codes from LTBA in the period of 2008–2013. Different categories of TS such as TSSN (Thunderstorm & Snow), TSRA (Thunderstorm & Rain) events, moderate TS, VCTS (Thunderstorm in the Vicinity of the aerodrome) events. VCTS is reported if a TS is in the range of 16 km from the airport but not greater than that range (MGM, 2010). It is widely accepted that thunderstorms exist if TS and one of its combinations with other events is reported at least in one report. The duration of TS is based on RE (recent) past weather group in METAR and SPECI reports. But the duration of VC events is still determined by consecutive reports because it does not have a past weather identifier. It is considered as one-minute duration if the VC event is reported only in one METAR or SPECI report.

Sounding data and CAPE / CIN values from University of Wyoming website (Url-7) in respect of Istanbul have been used to calculate the CAPE and CIN values (downloaded CAPE / CIN values and sounding data). Furthermore, sounding data closest to the observation time of TS in METAR and SPECI reports and maximum CAPE and matched CIN values in the event day are taken into account.

For weak convection CAPE is usually less than 1000 J/kg, while for strong convection CAPE can be 2500-4000 J/kg. In this paper, CAPE values are classified according to Table 3.1 (Wallace and Hobbs, 2006; Url-8).

3.3 Results and Discussion

A total of 88273 reports belonging to LTBA are examined in the period 2008–2013. In the study period of 1827 days, 87628 reports are METAR and 645 are SPECI (Table 3.2). Unfortunately, 12 in 2008, 1 in 2009, 3 in 2010, 52 in 2012 and in total 68 METAR reports are missing. Monthly and seasonal distribution of TS days over LTBA have been tabulated in Table 3.3. Autumn season has the highest TS frequency of 43 days of which September accounted 22 days in the 5 year period of study. Winter season has the lowest frequency of TS days. The year 2011 had the smallest number of TS days (11 days) while the year 2009 had the maximum TS occurrence (34 days).

Further analysis revealed that the highest frequency of TS occurred between 1800 UTC and 1859 UTC followed by 2100 - 2159 UTC and 1700 - 1759 UTC. The lowest frequency of TS events was observed between 0600 UTC and 0659 UTC. The maximum duration is 52 hours 15 minutes in September and the minimum duration is 4 hours 46 minutes in February.

The CAPE and CIN values have been collected from the University of Wyoming website and analysed for closest TS events. Also the maximum CAPE value of TS day has been analysed. The mean of the CAPE value closest to the TS time is 292.80 J/kg and the mean of corresponding CIN values is -50.50 J/kg. The mean of maximum CAPE values in 127 days is 359.28 J/kg and the mean of corresponding CIN values is -53.46 J/kg. The highest CAPE of 2529.12 J/kg was observed on August 7, 2009.

Non-TS days average CAPE is 83.17 J/kg and average CIN is -43.49 J/kg during 2008-2013.

Yearly and seasonal distribution of CAPE, CIN and their maximum values closest to TS events in the day occurred at LTBA in the period 2008–2013 are shown in Table 3.4. It can be seen easily in Table 3.4 that the maximum CAPE values are calculated in summer and minimum CAPE values are in winter. The summer mean of CAPE values in 2009 is 1018.21 J/kg and the CAPE(max) mean (CAPE(max) value is the highest CAPE value seen in the day) is 1058.91 J/kg. This is the maximum value over the entire 5-year period (Table 3.4b).

CAPE and CAPE(max) values are classified according to Table 3.1 (in the "Data and Methodology" section). The number of days for moderate convection (Between 1000 J/kg and 2500 J/kg) is 9 and 13 days according to Table 3.5 and Table 3.6, respectively.

3.4 Tables

Table 3.1 : Classified CAPE values.

Index	Value (J/kg)	Interpretation
Convective Available Potential Energy (CAPE)	0 < CAPE < 1000	weak convection
	1000 < CAPE < 2500	moderate convection
	2500 < CAPE < 4000	strong convection
	4000 < CAPE	extreme convection

Table 3.2 : METAR and SPECI reports, 2008-2013.

Year	Day Number	METARs	SPECIs	Total
2008	366	17556	107	17663
2009	365	17519	134	17653
2010	365	17517	118	17635
2011	365	17520	129	17649
2012	366	17516	157	17673
Total	**1827**	**87628**	**645**	**88273**

Table 3.3 : Monthly and seasonal distribution of TS days over LTBA, 2008-2013.

	Winter				Spring				Summer				Autumn				
Year	**Dec**	**Jan**	**Feb**	**Total**	**Mar**	**Apr**	**May**	**Total**	**Jun**	**Jul**	**Aug**	**Total**	**Sep**	**Oct**	**Nov**	**Total**	**Tot.**
2008	0	0	2	2	3	0	2	5	3	3	1	7	3	1	2	6	20
2009	4	0	0	4	6	2	0	8	2	4	2	8	8	3	3	14	34
2010	1	3	2	6	2	1	1	4	9	4	1	14	4	3	1	8	32
2011	0	0	0	0	0	1	0	1	4	1	0	5	2	3	0	5	11
2012	5	0	0	5	1	5	5	11	1	0	3	4	5	4	1	10	30
Total	10	3	4	17	12	9	8	24	19	12	7	38	22	14	7	43	127

Table 3.4 : The mean of CAPE, CAPE(max) and corresponding CIN values of TS days during 2008-2013.

2008	**CAPE**	**CIN**	**CAPE(max)**	**CIN**
Spring	62.55	-33.33	109.79	-15.46
Summer	434.00	-36.73	633.22	-24.69
Autumn	112.31	-35.59	378.70	-47.26
Winter	0.00	0.00	6.61	0.00

a)

2009	**CAPE**	**CIN**	**CAPE(max)**	**CIN**
Spring	4.14	-6.35	10.21	-11.71
Summer	1018.21	-54.70	1058.91	-52.88
Autumn	245.46	-54.27	279.82	-50.54
Winter	3.13	-21.48	5.92	-75.48

b)

2010	**CAPE**	**CIN**	**CAPE(max)**	**CIN**
Spring	28.04	-123.50	28.09	-123.71
Summer	540.04	-62.26	659.07	-59.89
Autumn	254.99	-71.39	266.45	-73.06
Winter	30.63	-18.88	44.67	-30.46

c)

2011	**CAPE**	**CIN**	**CAPE(max)**	**CIN**
Spring	0.00	0.00	0.08	-119.92
Summer	462.73	-15.46	557.89	-146.03
Autumn	193.47	-112.50	202.51	-110.25
Winter	-	-	-	-

d)

2012	**CAPE**	**CIN**	**CAPE(max)**	**CIN**
Spring	189.18	-36.65	214.54	-60.01
Summer	617.15	-118.40	807.04	-45.02
Autumn	373.68	-73.34	429.20	-33.31
Winter	14.01	-28.37	89.39	-10.82

e)

5 Years Avg.	**CAPE**	**CIN**	**CAPE(max)**	**CIN**
Spring	56.78	-39.97	72.54	-66.16
Summer	614.42	-57.51	743.22	-65.70
Autumn	235.98	-69.42	311.34	-62.89
Winter	11.94	-17.18	29.32	-29.19

f)

Table 3.5 : Classification of CAPE values.

CAPE J/kg	**DAYS**	**Avg. CAPE**	**Avg. CIN**
0 < CAPE < 1000	117	199.34	-49.26
1000 < CAPE < 2500	9	1259.30	-72.18
2500 < CAPE < 4000	1	2529.12	-0.18
4000 < CAPE	-	-	-

Table 3.6 : Classification of CAPE(max) values.

CAPE J/kg	DAYS	Avg. CAPE(max)	Avg. CIN
0 < CAPE < 1000	113	234.67	-53.70
1000 < CAPE < 2500	13	1275.52	-55.45
2500 < CAPE < 4000	1	2529.12	-0.18
4000 < CAPE	-	-	-

3.5 Figure

Figure 3.1 : The location of LTBA and Kartal Station (source: Google Earth, 2015).

4. FOG ANALYSIS AT ISTANBUL ATATURK INTERNATIONAL AIRPORT [3]

4.1 Introduction

Fog is one of the major meteorological phenomena that impacts human activities. The reduction of horizontal and vertical visibility due to fog causes problems for land, sea and air transportation. Transportation disruptions, cancellations and accidents are issues that can result from fog. At airports, fog can lead to the cancellation of flights, a decrease in the velocity of air traffic, diversions of flights to other airports and, most importantly, flight blocker events.

The weather phenomenon called ‘fog’ is a result of cloud water droplets or ice crystals suspended in the air at or near the land surface in which the observed visibility for aviation falls below 1000 metres (m). Similarly, ‘mist’ is formed when the observed visibility is between 1000 and 5000 m (Annex-3 ICAO, 2013; Glossary NOAA, 2014). It is important for the aviation industry to properly define fog and the lowering of the cloud base because of the impact on runway visibility. Other weather phenomena that can affect visibility are combinations of rain, drizzle and snow (Pearson, 2002).

To quantify weather-related aviation fatalities, Pearson (2002) analysed general aviation and small aircraft transportation data for the United States (including Alaska and Hawaii–and coastal waters) for the period 1995 to 2000. The data show that 4,018 people were killed in plane crashes, of which 1,380 were caused by weather events. Of these fatal accidents, 63% were caused by low cloud base and visibility, 18% by wind and turbulence, 8% by icing, 5% by rain and snow, 5% by thunderstorms and 1% by other weather events (Pearson, 2002).

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[3] This chapter is in queue for publishing :

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Çamalan et al. (2010), in a study of Ankara Esenboğa International Airport, classified fog according to temporal and spatial variability for the period of 2000 to 2009. The study showed that 77% of the fog formed as freezing fog (forms at temperatures below 0°C) and 23% as warm fog (forms at temperatures above 0°C) in this period. Approximately 50% of the fog was observed between December and January (Çamalan et al., 2010).

Van Schalkwyk and Dyson (2013) used 13 years of hourly data (1997–2010) for Cape Town International Airport to assess the mechanism of fog formation and its classification. They found 3 types of fog and their formation mechanisms and examined them by using many synoptic charts and an artificial neural network system.

De Villiers and Van Heerden (2007) performed a fog analysis for Abu Dhabi International Airport. They found 552 fog cases between the years of 1982 and 2003 and investigated them by making 'surface analyses'.

There are several other studies using fog analysis, forecasting and statistical classification at major international cities and airports. These include studies by Friedlein (2004), Galvin (2004), Hiscott (2006), Tardif and Rasmussen (2007), Stolaki et al. (2009), Roquelaure et al. (2009), Aktaş and Erkuş (2009), Roach (2012), and Jenamani (2012).

In this study, statistical analyses were used to investigate foggy days at Istanbul Ataturk International Airport (LTBA) for the period 2006–2015. The objectives of the study were to:

- Classify the fog that occurred at LTBA according to its formation mechanism.
- Classify the fog by the Instrument Landing System (ILS) category for aircraft.
- Identify the aviation landing approach categories (CAT operations) for foggy hours at LTBA.

4.2 Data and Methodology

LTBA is located southwest of Istanbul and north of the Marmara Sea (40°58′34″N 028°48′50″E) and is the largest airport in Turkey. The airport has an approximately 10,000 square metre (m^2) modern passenger terminal with a height of 49.75 m above mean sea level (AMSL). The airport has three different runways in an area. The length of runway 05-23 is 2580 m. Section 05 is 28.2 m (92.3 ft) AMSL and Section 23 is 27.5 m (90.0 ft) AMSL. Runway 17-35 is 3000 m long and consists of two sections, left and right. Section 17L (left) is 47.9 m (157.0 ft) AMSL and 17R (right) is 49.75 m (163.0 ft) AMSL. Section 35L (left) is 31.0 m (102.0 ft) AMSL and 35R (right) is 30.4 m (100 ft) AMSL. The LTBA runway locations are shown in Figure 4.1.

In this study, the occurrences of fog and low-level clouds at LTBA over a ten-year period (2006–2015) were examined. The occurrences were examined at yearly, monthly, daily and hourly (UTC-Universal Coordinated Time) frequencies. The data used in the study were half-hourly Aerodrome Routine Meteorological Reports (METAR) and Aerodrome Special Meteorological Reports (SPECI). The data were obtained from the Automated Weather Observing System (AWOS) operated by Vaisala.

The greatest distance from the airport surface visible for half or more of the horizon is called the ‘prevailing visibility’. The ‘minimum visibility’ occurs when visibility is below 1500 m or is less than 50% of the prevailing visibility. The Runway Visual Range (RVR) is used to support precision landing and take-off operations at airports. When the prevailing visibility or minimum visibility falls below 1500 m, (or when the visibility drops below 1500 m on the runway) the Runway Visual Range is reported (Annex-3 ICAO, 2013). The RVR is measured by a ‘transmissometer’ device (also known as an RVR device). At many airports today, low-visibility events are detected and described using the AWOS and an RVR device.

In this study, METAR, SPECI, prevailing visibility and RVR data were used. If a prevailing visibility observation was less than 1000 m, it was accepted as a ‘foggy’ observation according to the definition of fog (NOAA Glossary, 2014). Cases in which the prevailing visibility was below 1000 m and the RVR value was above 1000 m were also evaluated.

Fog can be divided into four types according to its formation mechanism (Tardif and Rasmussen, 2007; Stolaki et al., 2009; van Schalkwyk and Dyson, 2013). The four types are as follows:

- **Advection fog.** When a hot and humid air mass moves over a cold surface, the air cools. If the air mass temperature drops below the dew point temperature, advection fog is formed. If the wind speed is greater than 4 knots (kn), the sky is clear or the cloud base height is less than 700 ft before 1 hour of fog onset, the visibility can be reduced suddenly.
- **Radiation fog.** On clear and windless nights, the air near the earth's surface cools because of long-wave radiation loss. In this situation, radiation fog occurs. The optimal conditions for radiation fog include wind speeds less than 5 kn, clear skies or a cloud base height less than 400 ft before 1 hour.
- **Descent of cloud base fog.** Fog is formed when the cloud base **descends** to the surface.
- **Precipitation fog.** The presence of fog during precipitation or 1 hour after precipitation has stopped.

The fog at LTBA was classified using the four fog types. In addition, for the purpose of classifying approaching and landing operations, observations of fog events were classified according to the flight categories.

4.3 Result and Discussion

The total number of foggy days at LTBA was 49 days for the ten-year study period (2006–2015). The distribution of foggy days by year is shown in Figure 4..

Figure 4. shows in 2007, the maximum number of foggy days was eight. This was the highest number of foggy days observed in one year of the study period. The lowest number of foggy days was observed to be three in 2012. The average number of foggy days was 4.9, and a decreasing linear trend in the number of foggy days was observed in the study period.

Figure 4. shows the distribution of foggy days by month at LTBA for the study period. Figure 4. shows that 28.6% of foggy days at LTBA occurred in November, which was the foggiest month in the study period. The number of foggy days in

November was increased because Istanbul and the surrounding area remained under the influence of a high pressure system on a synoptic scale over an extended period (7 days) in November 2009. In total, 20.4% of foggy days occurred in January, 16.3% occurred in February and 12.2% in December. Fog did not occur in July, August or September during the study period.

Hourly METAR observations, which were made 20 and 50 minutes past every hour according to UTC, were used to show the frequency of fog occurrence. The distribution of foggy observations by hour at LTBA is shown in Figure 4..4.

Figure 4. shows that the maximum occurrence was 4.87%, at 0050 UTC. There was no fog from 1050 UTC to 1320 UTC.

Figure 4. shows the distribution of foggy METAR observations according to the prevailing visibility at LTBA. Figure 4. shows, for the 308 METAR observations made in the study period, the prevailing visibility was below 1000 m and fog formed. The prevailing visibility was 400 m for 24.03% of METAR observations, 300 m for 19.48%, and 200 m for 10.39%.

The RVR values for runway 35R, where the prevailing visibility indicated foggy METAR observations, are shown in Figure 4.. Figure 4. shows that for 11.36% of the 308 METAR observations, the measured RVR values were 1000 m or more for runway 35R. For 88.64%, the RVR values were measured at less than 1000 m. In cases where the cloud base (measured by a ceilometer device connected to the AWOS system), prevailing visibility, or (particularly) the RVR value is low, an Instrumental Landing System (ILS) is used at most airports. The ILS allows the plane's safe landing with the help of electronic devices. There are three types of ILS. The ILS used is determined by the Decision Height (DH) and RVR. The DH is a specified altitude at which, if the runway is not visible to the pilot, the implementation of the ‘missed approach’ plan should be started (Annex-3 ICAO, 2013). One of the ILS types is also divided into three sub-categories (Annex-6 ICAO, 2010). The ILS categories are:

- CAT I: DH ≥ 60 m (200 ft), Prevailing Visibility ≥ 800 m or RVR ≥ 550 m.
- CAT II: 60 m (200 ft) > DH ≥ 30 m (100 ft), 550 m > RVR ≥ 350 m.
- CAT IIIA: 30 m (100 ft) > DH ≥ 15 m (50 ft), 350 m > RVR ≥ 200 m.

- CAT IIIB: DH <15 m (50 ft), 200 m > RVR ≥ 50 m.
- CAT IIIC: DH=0, RVR=0.

An analysis of the DH and RVR data were undertaken to determine the use of ILS on runways at LTBA. runway 35L required CAT I, 35R required CAT II and runway 05 required CAT IIIC operation ILS in the study period.

The RVR data were available for runway 35R, corresponding to all 308 of the METAR observations. For runway 35L, the data corresponded to 307 of the METAR observations. They were also available for runway 05 in 253 of the 308 METAR observations. The lowest RVR values measured were 125 m for runway 35R, 125 m for runway 35L and 100 m for runway 05. The highest values measured for all three runways were over 1500 m.

Figure 4. shows the amount of cloud cover and cloud height when foggy METAR observations occurred as a result of low prevailing visibility. The following abbreviations are used:

- **Sky Clear (SKC).** No clouds present.
- **No Significant Cloud (NSC).** No clouds of operational importance are detected.
- **FEW.** The sky was covered with clouds at a ratio of 1/8 or 2/8.
- **Scattered (SCT).** The sky was covered with clouds at a ratio of 3/8 or 4/8.
- **Broken (BKN).** The sky was covered with clouds at a ratio of 5/8, 6/8 or 7/8.
- **Overcast (OVC).** The sky was covered with clouds at a ratio of 8/8.
- **Vertical Visibility (VV).** The vertical visibility and height is x100 ft.

Figure 4. shows that the vertical visibility was found to be 100 ft at 48.70% of METAR observations and 200 ft at 23.05%. For 308 of the observations in which fog was indicated by METAR observations (according to DH values), the CAT I operation could be applied to 50.00% of the observations and the CATII operation to 99.35% of the observations. The operations CAT IIIA, CAT IIIB and CAT IIIC could be applied to all of the observations.

The temperatures when fog occurred were observed in the following proportion of METAR observations, given in Table 4.1. The largest percentage of fog observations

(15.6%) occurred at 8°C. The smallest percentage of fog observations (0.3%) occurred at 14°C, 17°C and 21°C.

Figure 4. shows atmospheric pressure during fog events as a result of low prevailing visibility. Figure 4. shows that during the study period, the lowest observed atmospheric pressure value was 1006 hectopascals (hPa) and the highest pressure value was 1036 hPa when fog occurred under low prevailing visibility. The greatest number of fog observations occurred at approximately 1029 hPa (11.69% of METAR observations).

Figure 4. shows wind direction during fog events as a result of low prevailing visibility. Figure 4. shows, for 29.22% of METAR observations, wind direction was coded as VRB, which means the wind was blowing from different directions. VRB is used to denote that the change in wind direction is 60 degrees or more but less than 180 degrees when the wind speed is below 03 knots. Regardless of the wind speed, VRB is also applied when the change in wind direction is 180 degrees or more (Annex-3 ICAO, 2013). In the study period, the wind blew from between 180° and 270° for 40.58% of the hours studied and between 330° and 350° for 17.21% of the hours studied.

Based on the 49 foggy days observed at LTBA over a 10-year period, according to the criteria described in the data and methodology section, the fog types were found to be 59.18% radiation fog, 36.73% advection fog, and 2.04% precipitation fog; 2.04% of fog occurred as a result of the descent of the cloud base to the surface. From a seasonal standpoint at LTBA, 37.93% of all radiation fog events happened in autumn, 34.48% in winter, 24.14% in spring and 3.45% in summer. November was the month where radiation fog was the most prevalent fog type, at 34.48%. The seasonal distribution of advection fog at LTBA is 77.78% of all fog events in winter, 16.67% in autumn, 5.56% in spring and no advection fog in summer. Advection fog was dominant in 33.33% of the fog events in January. When we look at the wind directions (with wind speed >4 knots) of foggy days observed at LTBA, 15.58% is between 100° and 270°, 14.29% is between 310° and 350°. No wind above 4 knots had other directions on foggy days. When the wind blew from between 210° and 250° (over the sea), 44.44% of the fog was advection fog; when the wind blew from between 330° and 350° (over land), 44.44% of the fog was advection fog.

The purpose of the use of CAT I, CAT II and CAT III operations, even in low visibility conditions, is to make a safe landing a normal operation. Although CAT I, CAT II and CAT III operations require a certain investment by the air transportation providers, they provide flights without any diversions throughout the year.

There are many differences among the CAT operations. CAT I and CAT II operations require a visual reference for manual landing at the Decision Height (DH) spot; however, all CAT III operations (CAT IIIA, CAT IIIB and CAT IIIC) do not require visual reference, and the landing is made by an automatic landing system. The implementation of all CAT operations depends on the following 4 items: aircraft, airport, flight crew and operators (managers) (Çakıcı et al., 2009).

Based on 308 METAR observations through 10-year period, 22.15% of flight operations at foggy times occurred for runway 3L by CAT I operation, 71.10% of flight operations for runway 35R occurred by CAT II operation, 97.63% of flight operations for runway 05 occurred by CAT IIIA operation, 100.0% of flight operations for runway 05 occurred by CAT IIIB operation. Furthermore, CAT IIIC operations also occurred.

4.4 Table

Table 4.1 : The temperature during fog events at LTBA (2006-2015).

Temperature (°C)	**Frequency (%)**
21	0.3%
17	0.3%
14	0.3%
13	0.6%
12	9.4%
11	12.0%
10	9.7%
9	9.1%
8	15.6%
7	10.1%
6	12.0%
5	9.1%
4	4.2%
3	5.8%
2	0.6%
1	0.6%

4.5 Figures

Figure 4.1 : The runway locations at LTBA (Google Earth, 2015).

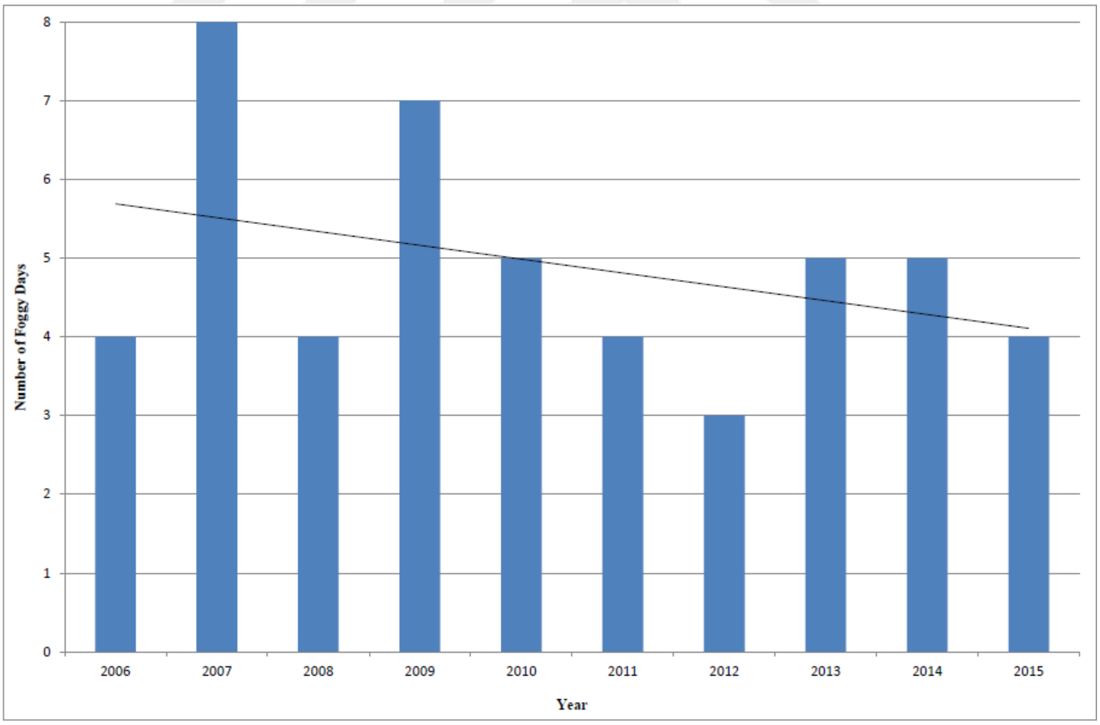

Figure 4.2: The distribution of foggy days by year at LTBA (2006–2015).

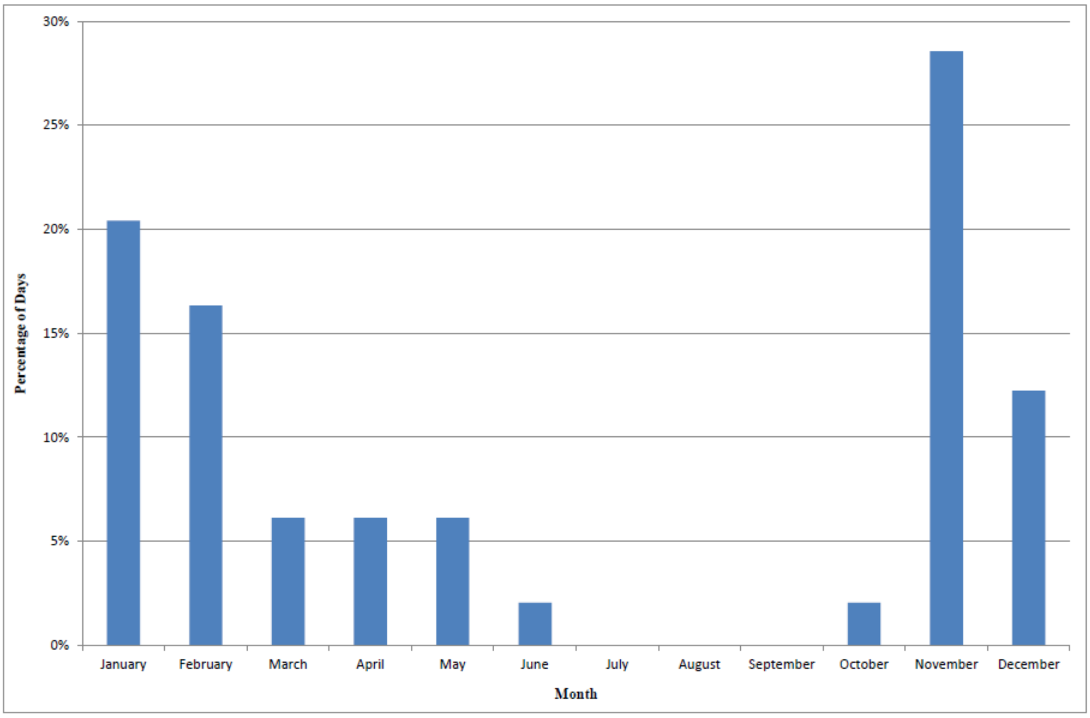

Figure 4.3 : The distribution of foggy days by month at LTBA (2006–2015).

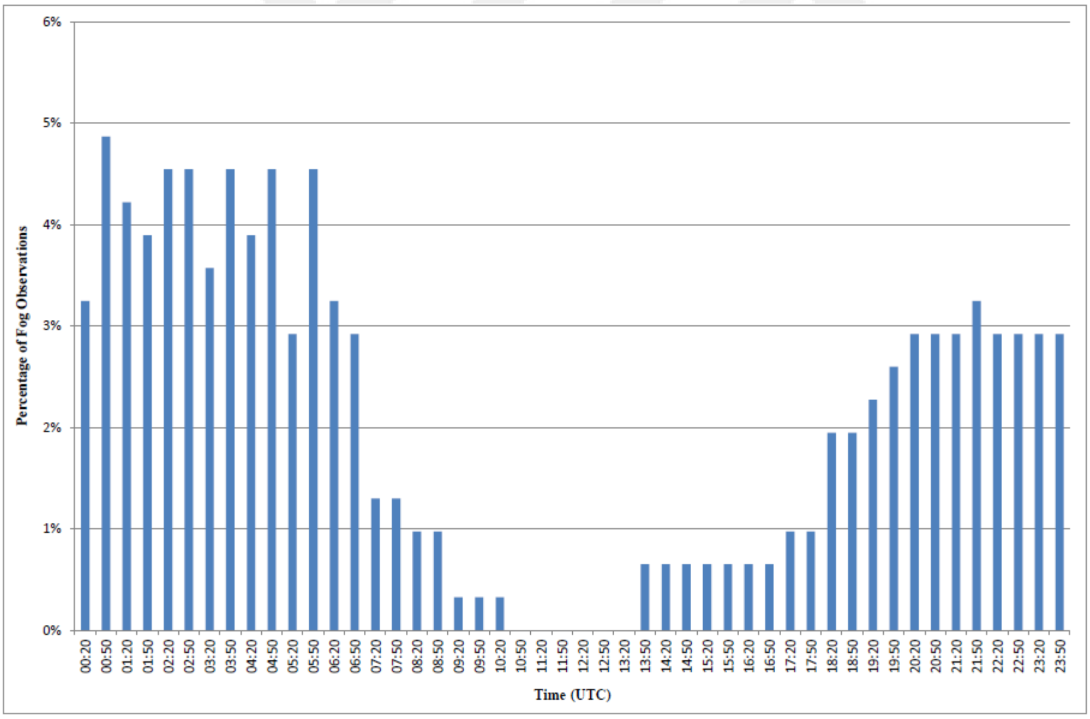

Figure 4.4 : The distribution of foggy observations by hour at LTBA (2006–2015).

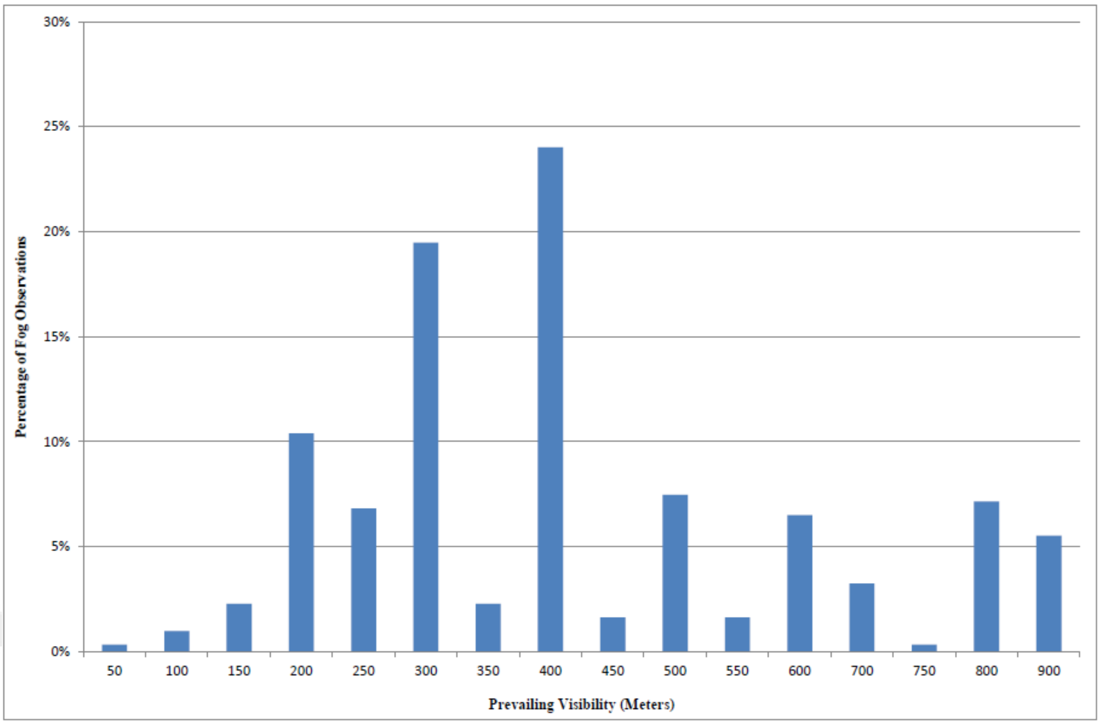

Figure 4.5 : The distribution of foggy METAR observations according to prevailing visibility at LTBA (2006–2015).

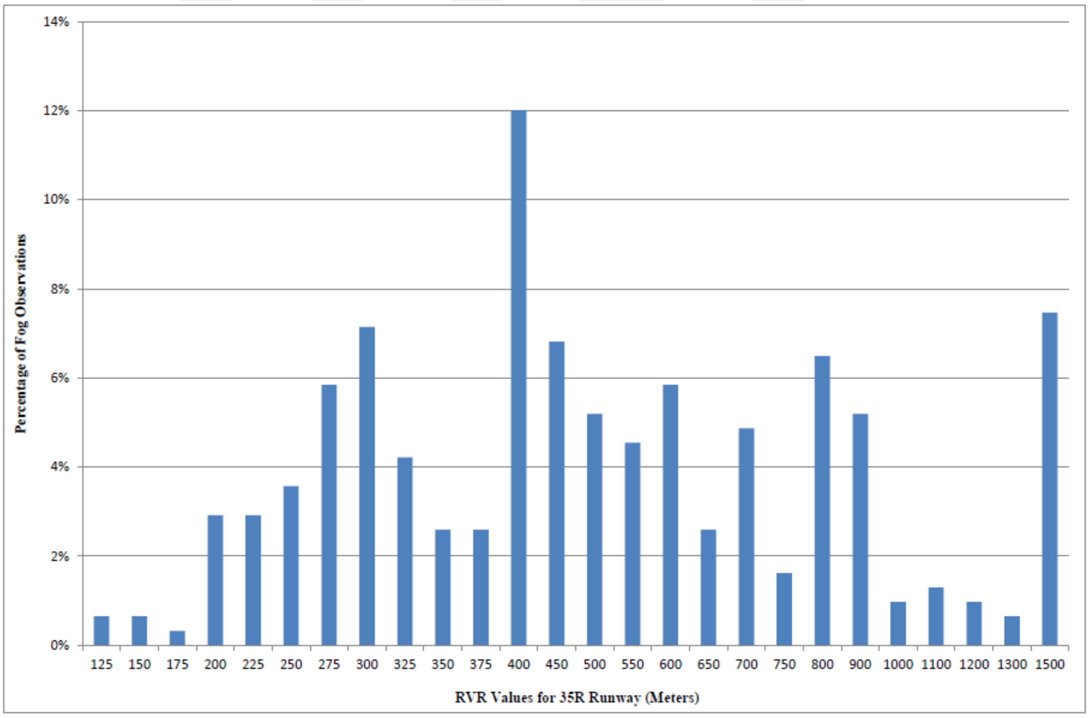

Figure 4.6 : Runway Visual Range values for runway 35R for foggy METAR observations at LTBA (2006–2015).

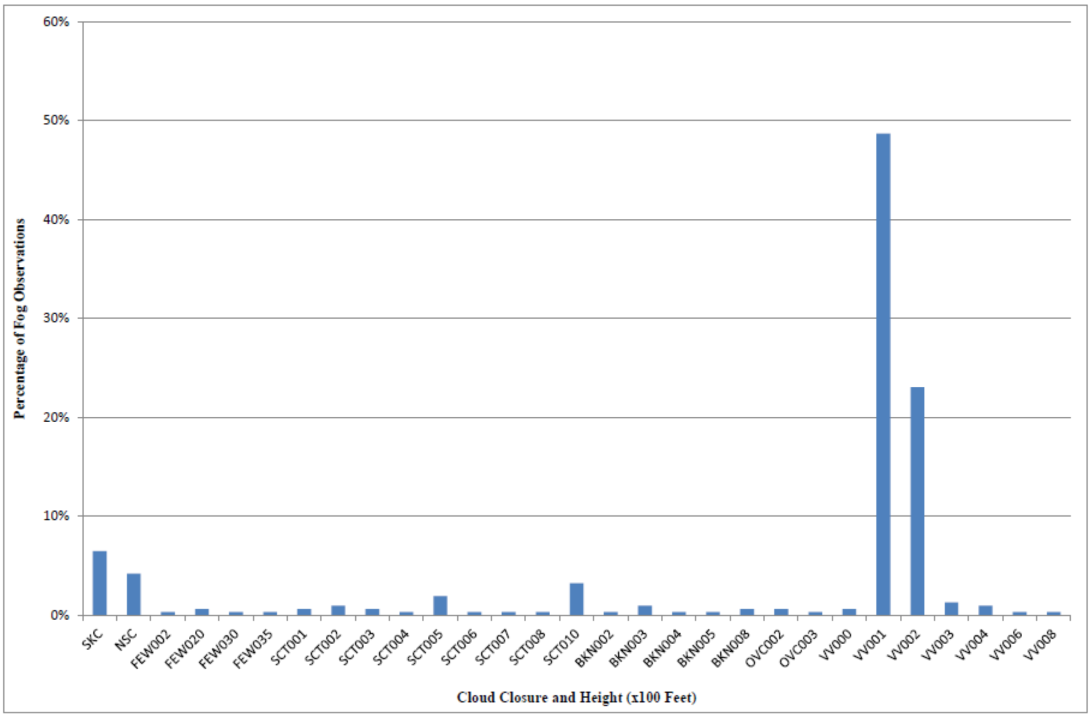

Figure 4.7 : Cloud cover and height during foggy METAR observations at LTBA (2006–2015).

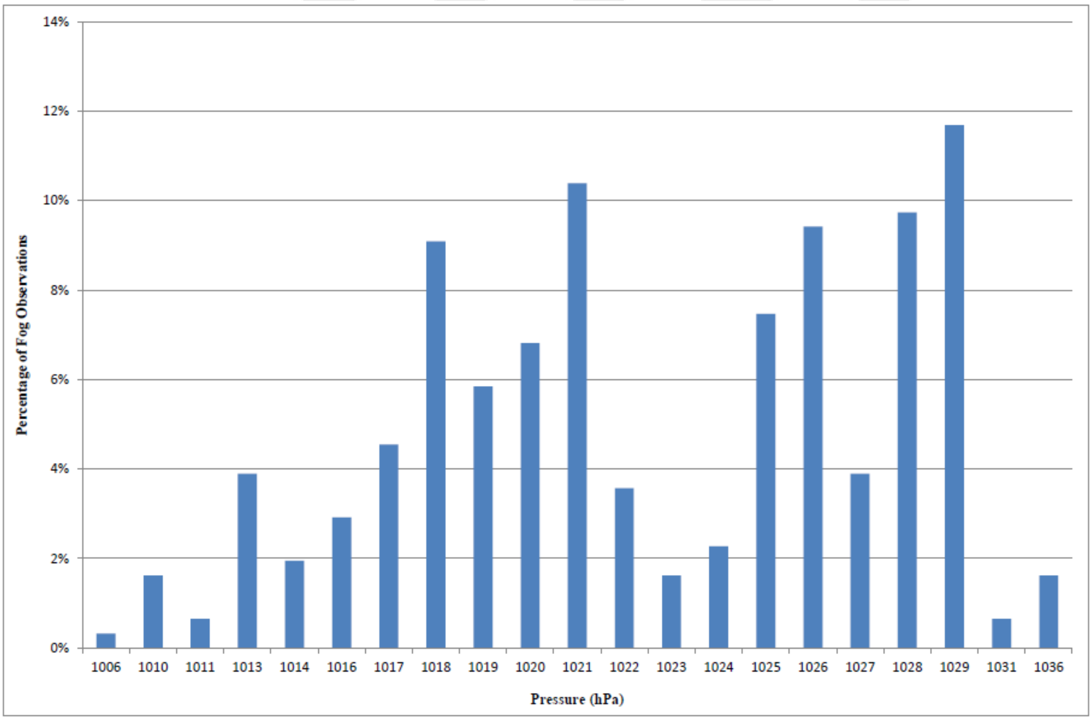

Figure 4.8 : Atmospheric pressure during fog events at LTBA (2006–2015).

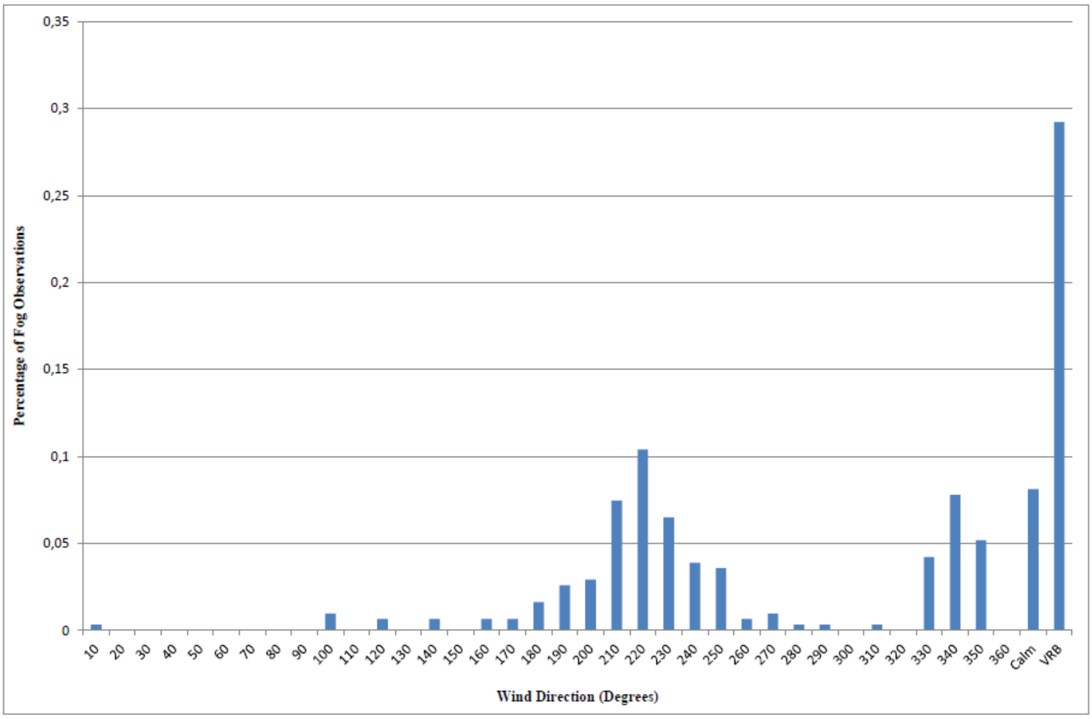

Figure 4.9 : Wind direction during fog events at LTBA (2006–2015).

5. THE EFFECT OF VOLCANIC ERUPTIONS ON TURKISH FIR AREAS: A CASE STUDY OF VOLCANIC ASH ON 14 APRIL, 2010 [4]

5.1 Abstract

Volcanic ash clouds could be drifted to hundreds, thousands of miles away and even intercontinental depending on meteorological conditions. They can have an effect over a very large air space. Ash clouds can drift over multiple countries, FIR (Flight Information Regions) and control areas and may cause danger. Volcanic ash clouds, which are effective in a very large area, have vital importance for aviation. Existence of volcanic ash clouds, or locating the dangerous areas may cause route changes, delays or even flight cancellations. In this study, the effect of volcanic eruptions between 2010-2015 in Turkish FIR areas were examined. The 5 year period of VAG (Volcanic Ash Graphic), which is designed by London Volcanic Ash Advisory Centre (VAAC) and works in coordination with Toulouse VAAC located in France, was used. In order to investigate the effects on Turkish FIR areas of Ankara FIR (LTAA) and Istanbul FIR (LTBB) areas, the SIGMET (Significant Meteorological Information) messages, which were generated by Esenboğa and Atatürk International Airport Meteorological Offices respectively, were examined. As the result of SIGMET messages generated by Atatürk International Airport Meteorological Office, flights between 10.000 and 30.000 feet altitude were cancelled in 18th April 2010 for northern Thrace and south west Black Sea region as well as in 19th of April 2010 for south west Black Sea region.

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[4] This chapter is published as :

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6. CONCLUSIONS AND RECOMMENDATIONS

The presence of a low-pressure system at ground level in Turkey in synoptic scale, the presence of high relative humidity values at the 700 hPa level (over 75%) over a large area of Turkey's mid-western part and the presence of unstable atmospheric conditions around Ankara according to the Skew-T Log-P analysis of Ankara led to the formation of convective activity around LTAC. The maximum temperature during the day was measured as 30.8 °C at 13:25 UTC. This value contributed to the increase in convection. MSG3 Natural Colour RGB, MSG3 Day Microphysics RGB/Summer and MSG3 Day Convective Storms RGB satellite images also support this convection. At 14:22 UTC, the Max radar product for LTAC, which has reached up 57 dBZ reflectivity value, shows the presence of severe precipitation and hail events. According to the METAR and SPECI reports, the severe thunderstorm event started at 14:32 UTC and ended at 14:50 UTC. The most effective time for a severe thunderstorm at the airport is 14:34 UTC. At this time a severe thunderstorm with hail and rain occurred at the airport, and prevailing visibility had dropped to 500 m. The wind gust value had risen 55 knots in value from 193 degrees for the 03-Right runway and had risen 61 knots from 196 degrees for the 03-Left runway. The 61 knots wind speed value was the highest measured value of severe thunderstorm transition. As a result of the passing of the thunderstorm cell from the southern to the northern runways at 14:37 UTC, 59 knots from 188 degrees and 56 knots from 175 degrees wind speed values were measured at 21-Right runway. Air pressure first dropped to 1004.32 hPa at 14:31 UTC and then quickly rose up to 1007.33 hPa at 14:34 UTC. In a three-minute period, there had been a rise in tendency of 3.01 hPa. The air temperature of 29.8°C at 14:21 UTC dropped to 11.4°C in a 15-minute period. (The total temperature decrease was approximately 18.4 °C). These data show that there was a gust front on the airport runways during the transition of a severe thunderstorm. During a two-minute period, 8 mm of rain fell, and in a 14-minute period, 16.2 mm precipitation was measured, and a severe thunderstorm event occurred at the airport during this time interval. A total of 16.4 mm of precipitation was measured in a 47-minute period (Özdemir&Deniz, 2016).

Ataturk International Airport (LTBA) recorded 127 TS days during 2008-2013 with Autumn having maximum frequency of 43 TS days and winter with a minimum frequency 17 TS days. Also, the duration of TS in Autumn season is the highest during the study period. The chance of TS is 6.95% in 1827 days in the 5-year period. TS events are mostly detected in Autumn (43 days) in the period but still maximum frequency of TS events differ as per years because atmospheric conditions causing TS show changes according to seasons and years. The least number of TS is in February (4 days) and January (3 days) while the most TS is in September (22 days) and June (19 days). 42.16% of TS events are between 1700 UTC and 2400 UTC and 17.48% are between 0900 UTC and 1300 UTC. The longest TS is on September 8 and 9, 2009 and June 23, 2010 in the 5-year period and its duration is 7 hours 30 minutes. The other long-lasting TS is on October 23, 2012 (5 hours 40 minutes), November 22, 2008 and November 23, 2010 (5 hours 30 minutes). These TS events continued without interval. The mean of the CAPE values to the TS time is 292.80 J/kg. The mean of maximum CAPE values in 127 days is 359.28 J/kg. But, non-TS days average CAPE is 83.17 J/kg during 2008-2013. The date of the maximum CAPE value in this period is August 7, 2009. The maximum CAPE value on August 7, 2009 is 2529.12 J/kg and CIN value is -0.18 J/kg. According to seasons, summer is the season that CAPE values are generally a maximum and winter is the season that CAPE values are a minimum. The mean of that is sounding values closest to METAR and SPECI reports. CAPE values are highest in summer and lowest in winter. CAPE value means are 434.00 J/kg in summer and 0.00 J/kg in winter of 2008; 1018.21 J/kg in summer and 3.13 J/kg in winter of 2009; 540.04 J/kg in summer and 30.63 J/kg in winter of 2010; 462.76 J/kg in summer of 2011; 617.15 J/kg in summer and 14.01 J/kg in winter of 2012. There are no TS in winter of 2011. The 5-year mean of CAPE values is 614.42 J/kg for summer and 11.94 J/kg for winter. The seasonal mean of maximum values in a day are 743.22 J/kg for summer and 29.32 J/kg for winter. The CAPE value means observed at Kartal Meteorological Station between 0-1000 J/kg, 1000–2500 J/kg and 2500–4000 J/kg are 199.34 J/kg, 1259.30 J/kg and 2529.12 J/kg, respectively (Özdemir et al., in press, a).

The total number of foggy days for the ten-year study period (2006–2015) at LTBA was 49 days. The foggiest year was 2007 (eight days), and the least foggy year was 2012 (three days). The mean number of foggy days over the ten-year period was 4.9

days. The incidence of fog according to the season was found to be 49.0% in winter, 18.4% in spring, 2.0% in summer and 30.6% in autumn. The maximum number of foggy days in a single month was in November (14 days). A decreasing linear trend of annual fog occurrences between 2006 and 2015 was observed. Fog incidents were observed in all 308 METAR observations. Of these observations, 88.96% were coded FG (Fog), 10.39% were coded BCFG (Fog patches) and 0.65% were coded PRFG (Fog partial). Analysis of annual fog events revealed that they were observed for the following durations (Özdemir et al., in press, b):

- **2006**. Four days for a total of 6 hours and 30 minutes.
- **2007.** Eight days for a total of 28 hours and 30 minutes.
- **2008**. Four days for a total of 13 hours.
- **2009**. Seven days for a total of 30 hours and 46 minutes.
- **2010**. Five days for a total of 24 hours and 54 minutes.
- **2011**. Four days for a total of 3 hours and 10 minutes.
- **2012**. Three days for a total of 4 hours and 27 minutes.
- **2013.** Five days for a total of 8 hours and 51 minutes.
- **2014.** Five days for a total of 30 hours and 03 minutes.
- **2015.** Four days for a total of 6 hours and 55 minutes.

For the study period, fog occurred on 49 days for a total of 157 hours and 6 minutes. Fog at LTBA is formed when the temperature is above 0°C (warm fog). The spread (the difference between the air temperature and the dew point temperature) was 0°C for 82.14% of 308 METAR observations, 1°C for 16.88% of 308 METAR observations and 2°C for 0.97% of 308 METAR observations. The longest foggy day occurred on 19 February 2014. On this day, the fog lasted for 15 hours and 23 minutes and occurred during the morning and evening. The second longest foggy day occurred on the 6 November 2010. On this day, the fog lasted for 15 hours and 05 minutes and occurred during the morning and evening. The formation mechanism of fog at LTBA was assessed; 36.73% of all fog was advection fog, 59.18% was radiation fog, 2.04% occurred due to the descent of the cloud base and 2.04% occurred due to rainfall. In one example, after 5.5 hours of light rain and fog, the prevailing visibility dropped 500 m and the pressure also dropped 1006 hPa. The temperature and dew point temperature were 13°C. In another example, fog occurring with the passage of a warm front continued for 30 minutes. To understand the typical approach and landing operations, an assessment of observed METAR data for a five-year period when fog occurred was completed. The assessment evaluated RVR and DH values according to the ILS. It was determined that flights that require ILS are landed under the following ILS categories (Özdemir et al., in press, b):

- 22.15% for CAT I.
- 71.10% for CAT II.
- 97.63% for CAT IIIA.
- 100.00% for CAT IIIB.
- 100.00% for CAT IIIC.

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CURRICULUM VITAE

Name Surname : Emrah Tuncay ÖZDEMİR

Place and Date of Birth : Ankara, 31.01.1970

E-Mail : etozdemir@gmail.com

EDUCATION :

- **B.Sc.** : 1993, İstanbul Technical University, Faculty of Science and Letters, Physics Engineering Department

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2011 – current, **Supervisor&Forecaster &Engineer**, Istanbul Ataturk International Airport Meteorology Office Yesilkoy/Istanbul/Turkey
- 2010 – 2011, **Supervisor&Forecaster &Engineer**, Kabul International Airport Meteorology Office Kabul/Afghanistan
- 2002 – 2010, **Supervisor&Forecaster &Engineer**, Istanbul Ataturk International Airport Meteorology Office Yesilkoy/Istanbul/Turkey
- 2000 – 2002, **Forecaster &Engineer**, Istanbul Ataturk International Airport Meteorology Office Yesilkoy/Istanbul/Turkey
- 1994 – 2000, **Forecaster &Engineer**, Bandırma Airport Meteorology Office Bandırma/Balıkesir/Turkey
- 1988 – 1988, **Observer**, Bandırma Airport Meteorology Office Bandırma/Balıkesir/Turkey
- Trident Jaguar 2016 **NATO Certificate & Letter of appreciation**, (May,12, 2016). Maslak/Istanbul/Turkey
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